ICSI 2014

Creating Infrastructure for a Sustainable World

Committee on Sustainability

Edited by
John Crittenden, Chris Hendrickson,
and Bill Wallace

ASCE

ICSI 2014

Creating Infrastructure for a Sustainable World

PROCEEDINGS OF THE 2014 INTERNATIONAL CONFERENCE ON SUSTAINABLE INFRASTRUCTURE

November 6-8, 2014
Long Beach, California

SPONSORED BY
Committee on Sustainability of the American Society of Civil Engineers

EDITED BY
John Crittenden
Chris Hendrickson
Bill Wallace

ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS

RESTON, VIRGINIA

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia, 20191-4382
www.asce.org/bookstore | ascelibrary.org

Any statements expressed in these materials are those of the individual authors and do not necessarily represent the views of ASCE, which takes no responsibility for any statement made herein. No reference made in this publication to any specific method, product, process, or service constitutes or implies an endorsement, recommendation, or warranty thereof by ASCE. The materials are for general information only and do not represent a standard of ASCE, nor are they intended as a reference in purchase specifications, contracts, regulations, statutes, or any other legal document. ASCE makes no representation or warranty of any kind, whether express or implied, concerning the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed in this publication, and assumes no liability therefor. The information contained in these materials should not be used without first securing competent advice with respect to its suitability for any general or specific application. Anyone utilizing such information assumes all liability arising from such use, including but not limited to infringement of any patent or patents.

ASCE and American Society of Civil Engineers—Registered in U.S. Patent and Trademark Office.

Photocopies and permissions. Permission to photocopy or reproduce material from ASCE publications can be requested by sending an e-mail to permissions@asce.org or by locating a title in ASCE's Civil Engineering Database (http://cedb.asce.org) or ASCE Library (http://ascelibrary.org) and using the "Permissions" link.

Errata: Errata, if any, can be found at http://dx.doi.org/10.1061/9780784413814

Copyright © 2014 by the American Society of Civil Engineers.
All Rights Reserved.
ISBN 978-0-7844-1381-4 (CD)
ISBN 978-0-7844-7874-5 (E-book PDF)
Manufactured in the United States of America.

Preface

ASCE envisions engineers as “entrusted by society to create a sustainable world….” As both the stewards of the natural environment and the designers and builders of the built environment, we have both the expertise and responsibility to achieve a truly sustainable world that provides environmental, economic and social well-being, now and for the future.

The American Society of Civil Engineers (ASCE) is well known for bringing to the forefront new and important concepts and technical knowledge on subjects critical to the civil engineering profession. Its many specialty conferences are designed to educate the various civil engineering communities, including practitioners, public and private infrastructure owners, researchers, graduates and policy makers in the latest issues and advances being addressed and accomplished by the profession. This conference, titled the 2014 International Conference on Sustainable Infrastructure, was held on November 6-8, 2014, in Long Beach, California. The Proceedings of this conference are included in *ICSI 2014: Creating Infrastructure for a Sustainable World*.

The 2014 International Conference on Sustainable Infrastructure was organized by ASCE’s Committee on Sustainability and co-sponsored by Tianjin University China. To develop this conference, ASCE’s Committee worked closely with Dr. Guanyl Chen, the Dean of the School of Environmental Engineering and Sciences, Tianjin University. He is also a member of the Steering Committee for this conference. As an emerging economy and the most populated country in the world, China’s approach to and the lessons learned in the development of its infrastructure systems provides important knowledge for civil engineers and society around the world. Direct engagement with our Chinese colleagues for this conference has helped in the planning of a follow-on conference slated for China in 2016.

These Proceedings are a fulfillment of a key goal of this conference: to assemble and deliver a comprehensive assessment of the current state of sustainable infrastructure on a global scale. The conference brought together experts from around the world working to maintain and improve infrastructure performance in a changing operating environment. Today, engineers, academicians and other practitioners are facing difficult and unprecedented challenges in addressing a new reality for infrastructure planning, design, construction and operation. Decade after decade of dynamic economic development is changing the environmental and societal conditions under which infrastructure is supposed to be planned, designed, constructed and operated. It is also changing the cost and availability of critical resources such as fresh water and energy. There is reasonable doubt whether those past practices can or should be sustained. Indeed, there are questions about whether these solutions are sustainable from the perspective of social, environmental and economic outcomes. How to deal effectively with these changes is one of the most important engineering challenge of the 21st century. To adequately provide infrastructure solutions to our emerging needs, a broader perspective of understanding and delivering sustainable solutions will be a cornerstone of the civil engineering profession's contributions.

This conference began with a reality check, the importance of infrastructure to the U.S. and world economy and risks posed by a continuation of society's unsustainable engineering practices. At the opening plenary, leaders from the World Bank, China, the U.S. Department of Homeland Security, state, and local officials offered their unique perspectives on sustainability in the built environment. After the plenary, the conference split into three tracks of oral presentations and panel discussions covering a wide variety of subjects in sustainable infrastructure. Additional technical papers were also presented in a concurrent poster session.

The technical sessions of the conference began by looking at the current state of infrastructure and its relation to national competitiveness. Presenters described recent experiences in dealing with extreme hazards and weather events, and lessons learned on infrastructure resiliency. The conference then shifted from challenges to solutions, covering such topics as project challenges and barriers, financing, climate change mitigation and adaptation, application of the Envision™ sustainable infrastructure rating system, engineering education, sustainable project management, sustainable communities and the creation of eco-cities.

ICSI 2014: Creating Infrastructure for a Sustainable World includes all papers presented by the authors in the plenary and in the 24 technical sessions with podium presentations along with a poster session running concurrently. The technical papers are 5-12 pages long and describe in significant detail the results and findings from research- or practice- oriented projects of broad interest to the civil engineering community. Case examples are also included. Each of the papers accepted for podium or poster presentation were subjected to a detailed review by members of the Steering and Advisory Committee, along with other domain experts as needed. In total, over 100 papers were selected from over 350 abstracts submitted to the conference Technical Committee.

The undersigned editors on behalf of the Steering and Advisory Committees, and the American Society of Civil Engineers, wish to express our sincere thanks and appreciation to all the presenters who have contributed to the breadth and depth of vision in their papers. The editors also thank the reviewers and moderators for their efforts and support in making this conference and these Proceedings a reality.

John Crittenden
Chris Hendrickson
Bill Wallace

Organizing Committee

Conference Chair
William A. Wallace, M.ASCE, ENV SP

Honorary Vice Chair
Jiajun Li, President of Tianjin University

Technical Chair/Proceedings Editor
John Crittenden, P.E., M.ASCE, Georgia Institute of Technology

Sponsorship/Exhibits Chair
Peter Binney, P.E., ENV SP, M.ASCE, Merrick & Company

Local Organizing Committee Chair
Doug Sereno, P.E., ENV SP, F.ASCE, Port of Long Beach

Conference Steering Committee
Jim Balocki, P.E., M.ASCE, Chief Executive Officer, U.S. Army

Guanyi Chen, Professor of Built Environment & Equipment, Tianjin University

Chris Hendrickson, Ph.D., NAE, Dist.M.ASCE, Carnegie Mellon University

Katherine Sierra, The Brookings Institution

Rusong Wang, Director, Urban Systems Ecology, Chinese Academy of Sciences

Conference Advisory Committee
Bernard Amadei, Ph.D., NAE, Professor, Geotechnical Engineering and Geomechanics, University of Colorado at Boulder

David Carlson, A.M.ASCE, Vice President – Director of Sustainable Development, Parsons Engineering

Reggie DesRoches, Ph.D., M.ASCE, Karen and John Huff School Chair & Professor, School of Civil & Environmental Engineering

Aridai Herrera, President, Technical Council of UPADI

Arpad Horvath, Ph.D., M.ASCE, University of California

Committee on Sustainability
D. Michael Mucha, F.ASCE P.E., Chief Engineer and Director, Madison Metropolitan Sewerage District

ASCE Staff
Muhammad Amer, Director of Special Projects

Katie King, Coordinator, Conferences & Meeting Services

Donna Dickert, Acquisitions Editor

Kay Hathaway, Administrator, Sustainability

Lucy King, CMP, Senior Manager, Conferences & Meeting Services

Michael R. Sanio, F.ASCE, CAE, ENV SP, Director, Sustainability and International Alliances

Contents

Situation: Current and Projected

Sustainability and Competitiveness

Climate Change Mitigation and Adaptation

Challenges and Barriers

Financing Infrastructure Projects

Sustainable Cities

Materials, Tools, and Methodologies

Envision Rating System

Sustainability, Society, and Culture

Innovation

Cross-Cutting Issues

Research Needs and Advances

© ASCE 2014

Pavement Management for Honduras

Carlos Montoya Rodriguez, M.S.[1], Kadri Parris, M.S.[1], William Wolfe, P.E., Ph.D[1], Carlos Montoya Thumann[2]

[1]Department of Civil, Environmental and Geodetic Engineering, The Ohio State University 470 Hitchcock Hall, 2070 Neil Avenue Columbus, OH, USA.
email: montoya-rodriguez.1@osu.edu; PH: (614) 314-5027; email: wolfe.10@osu.edu PH: (614) 292-0790; email: parris.19@osu.edu; PH: (614) 314-5027.
[2]Association of Consultant Engineers, Colonia El Prado, Edificio Ambar, Tegucigalpa, Honduras, email: carlosmontoya@aci.hn; PH: (011) 504- 3192-9379.

Abstract

It can be argued that maintenance of road pavements is more critical for the longevity of this public asset as opposed to the actual construction which tends to attract more attention. In many developing countries such as Honduras, the absence or inadequacy of funding can undermine any effort to ensure optimal performance of the road over the course of its design life. This paper highlights the current efforts being made to preserve road assets in Honduras and proposes recommendations for this country to obtain a more competitive road network through a study of the best international practices as it relates to maintenance of roads. As of 2012, Honduras had an official road network of 14,648 km, of which only 3,361 km (23%) were paved. Honduras transports virtually all its freight and passengers on roads as a consequence of the abandonment of the rail network coupled with the high cost of air transportation. Accordingly, the operational quality of this mode of transportation is a fundamental factor in the country's economic development. Government agencies responsible for making investments in road construction and maintenance face the continual problem of insufficient funds. In recent years, the funding assigned for maintenance of the road network was less than 2% of the country's Gross Domestic Product. Further, overloaded trucks in Honduras became common because the axle load control stopped operating in 1995 and has never been reactivated. This lack of monitoring and enforcement has caused increased stresses in pavement structures and consequently accelerates failure. Ten years ago, traffic counts and evaluations of the physical state of the road surfaces were discontinued as important inputs when designing strategies for road investment. Recommendations are proposed to more effectively utilize limited budgets and reduce vehicular operating costs. These recommendations are based on the international experience in pavement management and evaluation procedures of pavement conditions with high performance equipment. A discussion on the condition of the pavements with the various experts in-country will be presented.

Introduction

Utilizing available pavement design guides such as the ones developed by The Asphalt Institute or by AASHTO (American Association of State Highways and Transportation

© ASCE 2014

Officials), a pavement structure can be designed for any desired life expectancy. However, this does not imply that the pavement will perform maintenance free during its design life. Even if all requirements are met at optimum levels some form of maintenance is necessary (AASHTO, 1998). The proposed recommendations to the pavement management in Honduras will demonstrate a foundation in which all decisions are based on sound engineering background or criteria. It is imperative for Honduran officials to establish a program to conduct the maintenance and rehabilitation of various pavements around the country. This system must be based on scientific data and the decisions must consider many factors including environmental issues, cost, political issues, availability of resources, and method of rehabilitation work. It is important to mention that all the information obtained and reported in this paper were gathered through interviewing many in-country experts and did not come from laboratory tests. These anecdotal references were helpful for an understanding of the current pavement management program in place. Once determined, the strengths and weaknesses are established and recommendations will be proposed to more effectively utilize the assigned limited budgets and reduce vehicular operating costs.

Maintenance of Roads

Experience has shown that deferred maintenance not only costs more but also increases the risk of accidents, deaths, public criticism and vehicle operating costs as the condition of the pavement deteriorates (ADB, 2003). A good pavement maintenance/management program can significantly prolong the useful service life of any pavement structure through the cautious selection of the most cost effective maintenance procedures to address the specific field conditions.

Preventive maintenance is usually less costly and is more cost effective than corrective maintenance. It is common practice in most public agencies to have an ongoing program for crack sealing and pothole repair. These two relatively simple procedures are possibly the most cost effective preventive maintenance options and can greatly extend the useful service life of any pavement structure by preventing intrusion of water into the underlying pavement structure (base and subgrade) (Eltahan et. al, 1999). The need for complex and more expensive maintenance treatment can be delayed if this relatively simple repair technique is correctly employed.

Available financial resources are always an important factor in determining the level of maintenance that can be performed within a specific period of time. In developing countries, it is necessary to use lower cost maintenance treatments as a temporary measure, pending the allocation of additional funds for a more extensive maintenance procedure. The majority of public entities apply some type of pavement rating system as an aid in prioritizing their main activities. Indicators such as the Pavement Condition Index and the International Roughness Index (IRI) are very helpful when developing realistic budget requirements and funding bodies are more receptive to budget requests when they are supported by data (Asselin, 1994).

© ASCE 2014

In Honduras, to efficiently use the limited funds for road maintenance, it is critical to carefully evaluate and determine the cause of stress before suggesting the proper maintenance procedures of each pavement section, and correct it, as simple pavement repairs may be ineffective or short lived.

Current State of the Roads in Honduras

As of 2006, no evaluation or classification of the condition of the national road network has been performed in Honduras (Regioplan, 2006). Government agencies such as the Management Planning and Evaluation Unit (UPEG) of the Ministry of Public Works, Transportation and Dwellings (SOPTRAVI) that historically used to conduct this type of assessment are no longer in receipt of the economic resources for this purpose.

For the characterization of the road network the Honduran government has used the HDM4 (Highway and Development and Management Model) developed by the World Bank (WB) and three relevant parameters to define the necessities for investment which are: condition of the roads, use of the roads, and cost of projects. In a more specific sense, this decision making tool considers prediction of the behavior of the roads essentially by its traffic volumes, structural capacity of the pavements, maintenance standards, and environmental conditions. Additional criteria include quantifying the benefits for the user such as the vehicular operational costs savings and travel time reductions (Bennett, 1996). The last evaluation of the road network was conducted in 2006 by Regioplan a private consultant company contracted by the government. It was determined that the road network, consisted of 14,037 km of which 2,976 km were paved roads with 27% in good condition (IRI value less than 3.5), 51% in regular condition (IRI value between 3.5 and 5), and 22% in bad condition (IRI value greater than 5). An IRI value of less than 3.5 m/km would classify as a road in good condition according to the conducted analysis. IRI is the international measurement of ride quality, the fundamental factor that affects the vehicular operational costs (Sayers, 1995). As it relates to the remaining 11,061 km of non-paved roads, 29% are in good condition, 40% in regular condition, and 31% in bad condition (Regioplan, 2006).

The vehicular operating costs in Honduras during 2013 for roads in good, regular and bad condition were reported by Efrain Bustillo, economist and analyst for UPEG/(SOPTRAVI) and are shown in Figure 1. Clearly as the conditions of the roads deteriorate, the vehicular operating costs will significantly increase. Additionally, as expected heavier vehicle types traversing bad condition pavements result in higher vehicle operating costs. This evaluation was also performed using the HDM4 model by the WB.

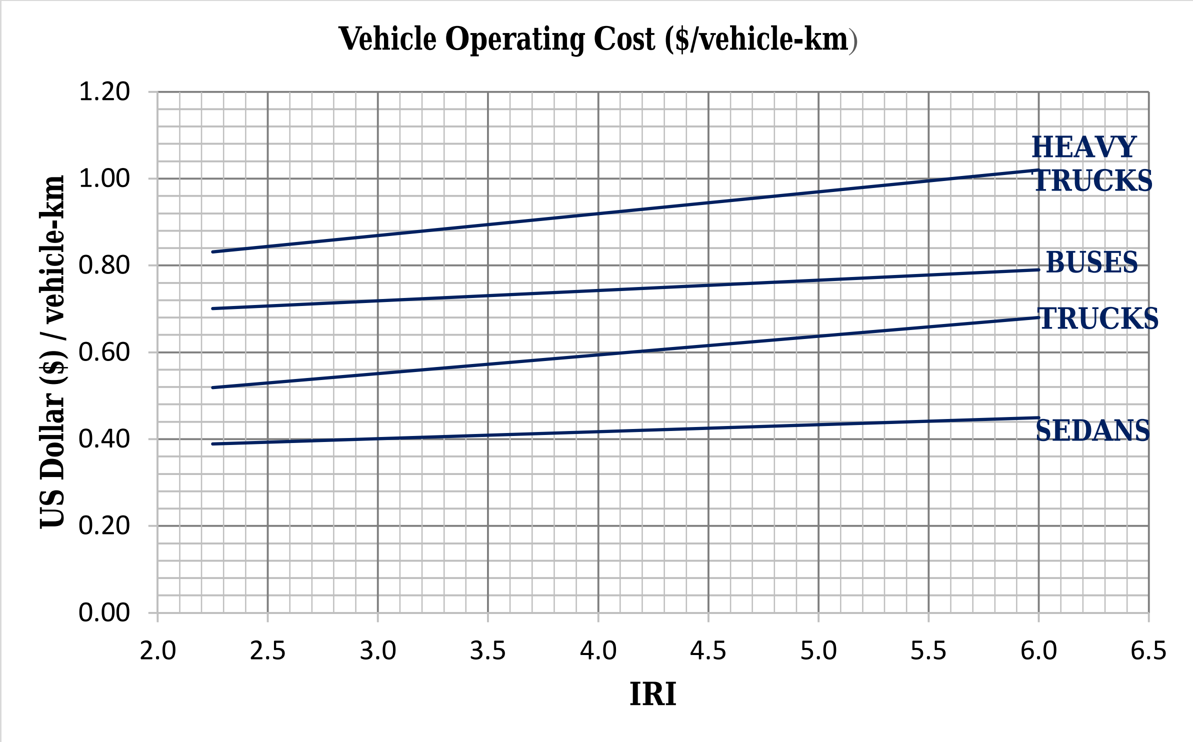


Figure 1. Vehicular Operational Costs Honduras for different classes of traffic 2013 (E. Bustillo, via e-mail, February 5, 2014)

The international financial organizations have always supported Honduras in the construction and rehabilitation of its road network, albeit the implementation of related projects between government and these financial entities can be a protracted process and delay the start of construction. It is imperative that both the Government of Honduras and the international lending institution devise a means of making this process more efficient.

Without the benefit of external funding, there is an internal funding mechanism which can contribute to maintenance activities. As expressed by Leticia Aguilar, ex-director of the Road Fund, Honduras has a law which facilitates the collection of a "Fuel Tax" for the funding of road maintenance. However, these funds are passed on to the General Fund of the State. As a result, the Road Fund, responsible for the maintenance of roads, does not receive the fuel tax to carry out its function since other sectorial areas such as education and health are given priority by the government when distributing the General Fund obtained from the "Protection of the Road Infrastructure" law. This prevents the Road Fund from engaging in any meaningful maintenance programs for the national road network (L. Aguilar, telephone communication, January 28, 2014). Figure 2 shows the declining percentage of funds assigned for the preservation of road assets vis-à-vis the total amount budgeted for this purpose by the Honduran congress.

© ASCE 2014

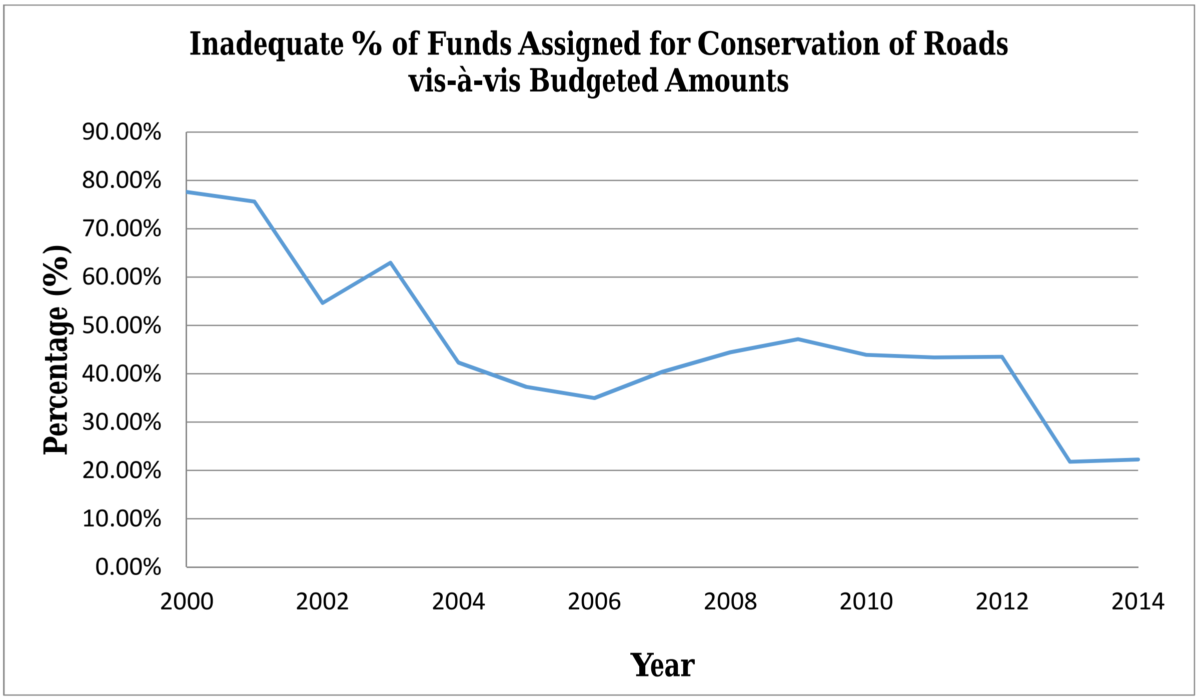


Figure 2. Percentage of Assigned vs Budgeted Funds for the preservation of Road Assets by the Honduran Congress (Leticia Aguilar, via e-mail, January 28, 2014)

In addition, Figure 3 shows the stark difference in dollar amounts between the actual and budgeted funds for road preservation in Honduras. This measured underfunding of road preservation works further compounds an already difficult monetary situation.

According to Fernando Bier, expert economist in transportation for Regioplan, Honduras at the present time requires an investment of US$ 150 million, for three consecutive years 2014-2016, to tune up all roads in the network to an acceptable level. However, in 2014, only US$ 38 million were assigned to resolve the problem of road maintenance (F. Bier, telephone communication, February 11, 2014).

During the period, 2008 to 2014, an investment of US$ 300 million was acquired to rehabilitate and expand several segments of the main road axis of the country, the road Tegucigalpa – San Pedro Sula - Puerto Cortés (295 km) (E. Bustillo, telephone communication, February 5, 2014). This was made possible with the support of the WB, Central American Bank for Economic Integration, Inter-American Development Bank and a grant from the Millennium Challenge Account. These represent significant investments for the pavement infrastructure of the country.

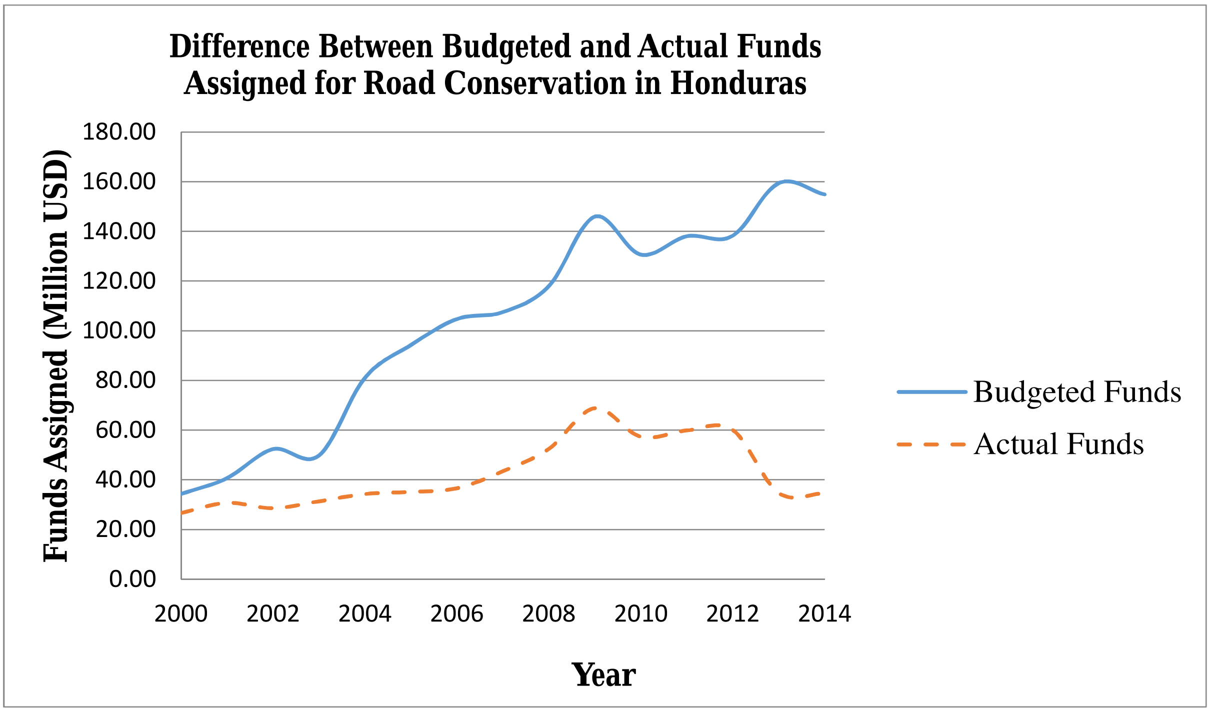


Figure 3. Actual vs Budgeted Funds for the preservation of Road Assets by the Honduran Congress (Leticia Aguilar, via e-mail, January 28, 2014)

The pavement infrastructure assets of Honduras are estimated at approximately US$ 1,400 million since there is no study to ascertain the true value (F. Bier, telephone communication, February 11, 2014). Considering that the nation does not have sufficient resources for the maintenance of roads, as well as the expansion of the road capacity for other routes, the government created COALIANZA, Commission for Promotion of the Public-Private Alliance, which at present has formalized the concession for two construction, expansion, and maintenance contracts which are:

1. The Logistics Corridor, Goascorán-Villa de San Antonio-San Pedro Sula- Puerto Cortés and Tegucigalpa-Villa de San Antonio (391.8 km), investment: US$ 90.5 million.
2. The Touristic Corridor of Honduras, El Progreso-Tela, San Pedro Sula-El Progreso and La Barca-El Progreso (122.6 km), investment: US$ 150.0 million.

At the present time Honduras does not have a pavement research center to investigate and analyze the pavement performance of the road network. In addition, information and data on the pavement infrastructure and highway network within Honduras are very limited and not well-organized. Pavement preservation techniques are not well understood within the transportation industry and state-of-the-art standards are nonexistent. The government has neither the technical expertise in pavements nor a comprehensive pavement management system to inform government decisions or actions that need to be taken for the preservation and maintenance of the pavement infrastructure.

© ASCE 2014

It has been approximately ten years since road assessments in Honduras have been done from explorations of pavements using high-performance equipment such as the Falling Weight Deflectometer (FWD) with the participation of foreign consultant companies. Recently, a local consultant company has acquired a new-generation FWD. This exhibits progress in the design and evaluation of pavement structures in the country by utilizing the Resilient Modulus of materials and not design values given by correlations with California Bearing Ratio.

For the design of asphalt mixes, the country does not have high-performance equipment to simulate and predict failures due to fatigue and deformations. The quality of the asphalt binders provided by distributors is currently not verified. The only requirement is the quality certificate that the same asphalt distributor provides which reflects a conflict of interest. All asphalt plants in Honduras use the Marshall Test Method, ASTM D1559, to design the mixes. While the Marshall Method has served a very useful purpose, it has long been recognized that it is an empirical test and does not provide certain engineering measurements that are necessary for an accurate prediction of long term performance. The Marshall Test does not measure the potential for fatigue cracking, thermal cracking and rutting. As a result of these deficiencies, the Strategic Highway Research Program (SHRP, 1986) undertook a five year, fifty million dollar research program to develop a new method of mix design along with new tests for evaluation of the asphalt cement (binder).

The most recent construction contracts in the country now requires the fulfillment of the IRI value of 2.0 m/km maximum for flexible pavements and 2.5 m/km maximum for rigid pavements (SOPTRAVI, 2010). This requirement had a positive impact as it resulted in the renovation of the construction equipment of the major construction companies.

Different factors affect the performance of a typical pavement structure. However, after discussing with interested parties, the consensus is that two of the major reasons for most pavement failures include heavy loads (i.e. over weight trucks and buses) and moisture. In the country the load restrictions are not followed and not enforced. This causes many stresses to pavement structures. The majority of the pavement design guides use traffic volumes as a critical part of the decision process to select the thickness of the pavement courses. The main criterion in this category is the truck percentage that the pavement will face in its life. In general, truck traffic is the major cause of the fatigue failure of any typical pavement. There is a relationship between the load carried by the truck and the damage caused to the pavement. This relationship is not linear and it is to the fourth power function (Molenaar, 1984). Therefore, any overloading will cause severe damage to the pavement.

The other factor that could be affecting the performance of the pavement structure is the presence of moisture. Moisture is present at many road project sites in many forms such as water coming down from mountains, water in dishes, etc. In some cases, the water coming down from the hill sides is used to wash cars and vans in the country. Another major cause of moisture entering granular base in pavements is vapor movement due to the high temperatures experienced in the country ranging from 26 to 40 °C. Due to all these factors it is very important to have a comprehensive drainage program for all pavements.

© ASCE 2014

Most of the pavement sections revealed evidence of alligator cracking from low to severe. This type of cracking can be classified as fatigue cracking that starts at the bottom of the pavement structure and ultimately propagates to the surface of the pavement. The traffic loading causes the cracks to connect creating a pattern similar to alligator's skin. The major reason for these types of failures is weak subgrades or subbase pavement layers as a result of inadequate thickness or presence of moisture (Tseng et.al., 1989).

Proposed Recommendations

The following recommendations are proposed in order to obtain a more competitive road network and are based on the deficiencies of the existing pavement management program:

1. With immediate effect, appropriate steps should be taken to re-establish a sustainable and robust vehicle weight control program aimed at ensuring that pavement systems do not experience stresses which are beyond that which they are designed to withstand. This program must place a premium on the enforcement component of this action in order to avoid premature failures.
2. Encourage and maintain private sector interest in Public-Private Alliances aimed at new road network concessions as well as reconstruction/rehabilitation of significant thoroughfares. This ensures that for an appreciably longer period of time, the roads are maintained in good condition (IRI less than 3.5) since this becomes a priority for private investors to protect their interests.
3. Ensure that through political will, legislative reform is undertaken where necessary to ensure that monies received through the fuel tax are funneled to road maintenance activities instead of being redirected to other sectors. This will not solve the financial difficulties in total but will make more money available for simple preventative road maintenance efforts.
4. Establish a pavement research center with state of the art equipment to investigate and analyze the pavement performance of the road network while strengthening institutional capacity among engineering personnel. The institutional capacity strengthening can be in the form of conducting in-country training for engineering and administrative professionals or investing in graduate education of young Hondurans at universities in the first world, who are then legally bonded to give a certain minimum number of service years to the country upon completion. These professionals will acquire proper education and training to become experts in areas such as: pavement materials, transportation, or pavement management systems.
5. Establish a comprehensive pavement management system for the county. This will enable decisions to be taken in a logical and systematic manner that will eventually save money in the long term. This type of system may take considerable time to develop. Several issues will be monitored and evaluated within the system including, but not limited to: inventory of all pavements; inspection of all major highways in the country; developing a maintenance and rehabilitation techniques; life-cycle-cost analysis; use of recycling materials; developing a comprehensive drainage program for all pavements in the country; and establishing a training program for all highway officials.

© ASCE 2014

6. Establish a revised pavement design system that considers many factors that are not properly determined at the moment such as the realistic loading conditions that exists in the country.
7. Establish a revised asphalt mix design that considers many variables including the moisture susceptibility of the mixtures. This may decrease the amount of the damage caused by the moisture to the future pavements constructed around the country.
8. Establish a program to test asphalt binders for physical and chemical properties. This testing could be accomplished every month until a trend has been achieved. In addition, random testing will be conducted to monitor if any changes are occurring so the mix design might be modified.
9. Resolve the drainage issues observed in various locations around the country. A comprehensive program to minimize the water movement throughout the pavements must be established as soon as possible.

Costs to cover most of the proposed recommendations could be obtained with the funds for institutional strengthening which are already included in the contracts with the international financial entities.

Conclusions

The pavement design philosophy currently employed by the government agencies in Honduras needs to be revisited and brought up to international best practice standards. The pavement design industry is slowly moving towards a more mechanistic approach which necessitates the determination of key design parameters. If this is adopted in Honduras, then the philosophy of design needs to extend to the accurate determination of the aforementioned parameters. Laboratory experiments and modern techniques are needed to ensure this goal is achieved. Better design of roads ensures that from the inception the susceptibility to failure is minimized.

Lack of effective leadership from engineering professionals to convince and influence relevant public officials, regarding the need to effectively appropriate all designated funds for the maintenance of roads, has created a situation where preservation of road assets is not treated as a priority. Lack of preventative maintenance effort has induced financial losses that progressively increases as pavement conditions deteriorate. This has resulted in subsequent damage to pavements in the road network and further increases in the vehicle operational cost for the motorist.

The public and private sectors, must continue to be involved in the construction and rehabilitation of roads through alliances to create a competent pavement management system for Honduras. This system must be designed in order to protect the road infrastructure that is a fundamental factor for the competiveness and development of the country.

© ASCE 2014

Acknowledgements

The authors would like to thank many people who were willing to give their time and resources for this paper. The author wishes to thank specially Leticia Aguilar, Efrain Bustillo, and Fernando Bier for their cooperation.

References

Asian Development Bank, (2003); “Road Funds and Road Maintenance: An Asian Perspective”. (This publication is available online at http:/www.adb.org).

AASHTO Guide for Design of Pavement Structures, (1998), American Association of State Highway and Transportation Officials, Washington, D.C.

Asselin, L. (1994), “Integrated Financial Management Systems: Experiences in Latin America”, World Bank (mimeo), Washington DC.

Bennett, C R, (1996). The New HDM-4 Model. Proceedings, Combined 18th ARRB Transport Research Conference and Transit New Zealand Symposium, Christchurch, New Zealand, Part 4 (Asset Management).

Eltahan, A.A., J.F. Daleiden, and A.L. Simpson, (1999) “Effectiveness of Maintenance Treatments of Flexible Pavements,” Transportation Research Record 1680, Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 18–25.

Molenaar, A.A.A., (1984), "Fatigue and Reflection Cracking Due to Traffic Loads," Proceedings of the Association of Asphalt Paving Technologists, Vol. 53, pp. 440-474.

Regioplan (2006). Revision of the Road Maintenance Plan, PMV 2007-2010, Final Report, July 2006, elaborated by Regioplan for the Road Fund.

Sayers, M. W. (1995). “On the calculation of IRI from longitudinal road profile.” Transportation Research Record 1501, Transport Research Board, Washington, DC.

“Strategic Highway Research Program, Research Plans”, (1986), Report, Prepared by the University of Maryland Transportation Studies Center.

SOPTRAVI (2010), Road Tegucigalpa-Rio del Hombre Contract (24 kms), MCA-HONDURAS, 2010, Finish of the Tegucigalpa Beltway Contract (7 kms) SOPTRAVI, Honduras.

Tseng, K. and Lytton, R. (1989) Prediction of Permanent Deformation in Flexible Pavement Materials. Implication of Aggregates in the Design, Construction, and Performance of Flexible Pavements, ASTM STP 1016, ASTM, pp. 154-172.

© ASCE 2014

"Suburban Rail System - To the rescue of urban infrastructure crisis faced by the metropolitan cities in emerging economies"

Authors
Khader Basha Syed – kbsyed@praja.in
Capt. Naveen Chandra - capt.naveenchandra@gmail.com
Sathya Sankaran – sathya@praja.in
Sanjeev Dyamnnavar - sanjeev@praja.in
Founder Members, Praja-RAAG (Research, Analysis and Advocacy Group), Bangalore, India

Prof. T. G. Sitharam - sitharam@civil.iisc.ernet.in
Ex-Chairman, Center for Infrastructure, Sustainable Transportation and Urban Transport Planning (CiSTUP), Indian Institute of Science, Bangalore, India

ABSTRACT

This paper attempts to describe the benefits of using existing railway infrastructure around growing metropolitan cities for addressing urban mobility challenges. Suburban Rail Services can greatly help alleviate commuting options and meet rising demands for reliable mass transit services into and out from city centres to suburbs and satellite towns. Construction costs would be optimum and construction periods small in comparison with new systems. Increasing capacities with more frequent trains can be done sustainably and without causing disruption to other city facilities and infrastructure unlike road augmentation or building new routes for exclusive track guided rail systems.

A proposal for implementing 'Suburban Rail Services' in the city of Bangalore, India (population: 9.5 million) has been used as a case study. The socio-economic benefits that can be derived from such a system include the obviously easier access to city centers by suburbanites, minimizing city road decay due to overloads, address problems of people who are poor (not just in terms of income but also in terms of social exclusion associated with inaccessibility to jobs, schools, health facilities and social activities that are usually superior within the city) besides adding to the quality & quantity of public transport. It would also help shift many economic development activities away from the city and concentrate new development in nearby satellite towns.

KEYWORDS: Suburban Rail, Emerging Economies, Sustainable Transport, Mass Transit

© ASCE 2014

1 INTRODUCTION

Improved economic conditions in high population countries like India and China have led to a situation where cities in these countries are 'overloaded' starting with the larger ones first followed by others in "top first, bottom last" order dependent on existing city sizes – even as the larger ones continue their growth without halt. It goes without saying that economic and business opportunities tend to be created in the larger cities rather than uniformly across the country and as a result, cities have attracted huge numbers of rural migrants. Thus, none of the cities have stopped growing even after decades and such incessant growth has placed a tremendous strain on infrastructure, particularly urban transport infrastructure. Housing, health-care, education, transport, and entertainment have all become very expensive in these growth-oriented cities due to increasing demand.

Since a majority of the migrant labour force is usually poor, the demand for low priced housing is very high within cities, but such moderately priced housing is neither available nor affordable by migrants as land costs within the cities have risen to exorbitant levels. The only option is to find a means by which workers can gain access to job markets within cities whilst they are provided with an option to reside in suburbs where housing costs are generally much lower. If an efficient and affordable transport system is made available to connect city centres with suburbs, exclusion of low to moderate income people to the city and suburbs would be greatly reduced.

2 BANGALORE AT A GLANCE

Bangalore, capital of the state of Karnataka, India, is popularly known as "The Silicon Valley of India" since it is home to the largest number of Information Technology (IT) /Information Technology Enabled Services (ITES). The city exports over a third of all IT exports from the country. Post India's independence in 1947, the city became home to many large public sector enterprises. Most public sector industries built their own townships that included housing for employees and ran fleets of buses to transport employees from home to work and back. During the 1960s and 70s, the city was referred to 'Pensioner's paradise' due to its salubrious climate. Parks and gardens still dot the city and the presence of trees are still a pride to its residents.

Economic liberalization in 1990s catapulted the city to the forefront of growth and hundreds of multi-national firms set shop in the city to take advantage of the benefits offered with huge talent pools for engineering and other services. Within a span of some twenty-odd years, the city's population exploded, road traffic increased several fold and civic services began to get stretched. Urban transport was found wanting.

© ASCE 2014

2.1 Population

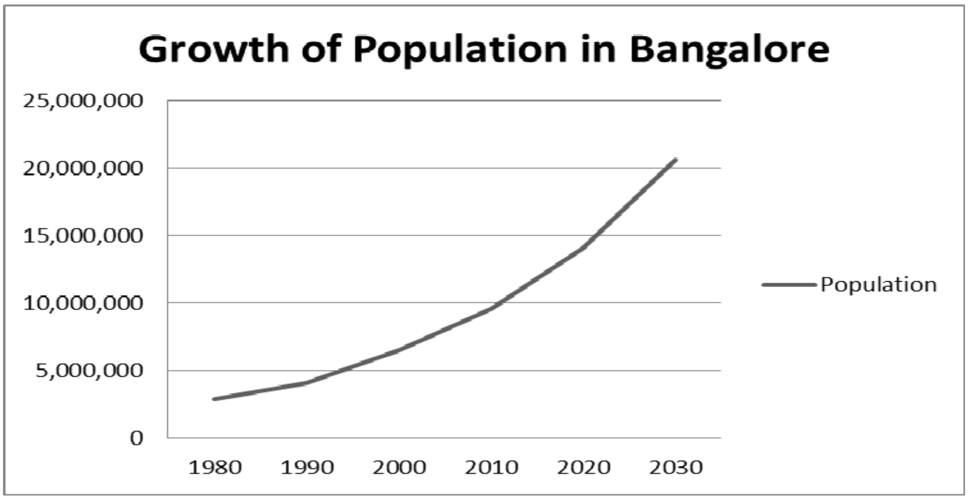


Figure 1: Bangalore Population – Current & Estimates[1]

In 2011, Bangalore had a population of 9.5 million – an increase of 46% in a single decade. The population is estimated to reach 14 million by 2020 and 20 million by 2030.

2.2 Bangalore's Motorization

In the absence of an efficient public transport system (other than street based buses), Bangalore has seen an exponential growth of private vehicles. By 2010, there was about one vehicle for every 2 persons, i.e. for a population of 9.4 million there were over 4 million vehicles. Assuming the same proportion of vehicles, it is estimated that by 2020 when population touches 14 million, there would be over 11 million vehicles and by 2030 (population 20 million), there would be 33 million[2] vehicles plying on the city's roads. Heavy traffic congestion across the city has been routine as is increasing levels of air pollution by vehicle emission. Road safety has deteriorated considerably.

These motorization patterns are similar to those in Eastern Europe but at much lower income levels. The explanation for this lies in the structure of the private vehicle fleet. Motorized two-wheelers are the main growth category with cars placed a distant second. Thus it is similar to that experienced in East Asian cities (e.g. Hanoi, Ho Chi Minh City, Kuala Lumpur etc). Motorcycle ownership runs very deep down the income ladder since many unskilled laborers, petty traders and shop keepers own or aspires to own two-wheelers due to decreasing costs of vehicle ownership in relation to other costs. In this context, it is similar to mobile phone ownership in the

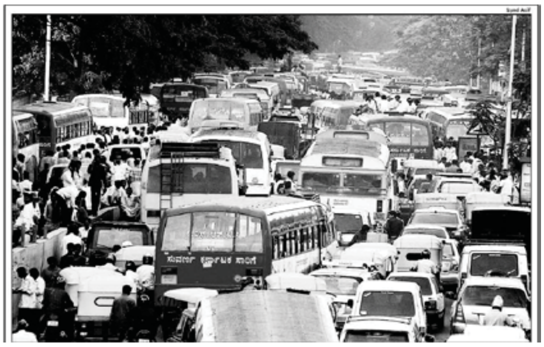
[1] Source – Census of India, 2012 RITES Report, Projections for 2020 and 2030 (calculated at 3.9% growth annually)

[2] Current Figures – Bangalore City Traffic Police, Projections for 2020 and 2030 – Calculated @ 11% annual growth.

© ASCE 2014

country as both (private vehicle and mobile phone) are considered necessities for individual economic progress. The consequences of two-wheeler primacy is a boon for the mobility of many people, but are unfortunately quite negative for traffic flow, safety and air pollution. This said, the split of daily travel by mode is still not dominated by motorcycles (or cars), but by public transport services.

2.3 Traffic and transport infrastructure



Picture 1 – Traffic Scenario on Bangalore Roads[3]

Picture 2 – Another view of Traffic Scenario in Bangalore

These pictures bear testimony to the levels of traffic congestion in Bangalore. The existing street-based public transport bus service is unable to meet the rising demands due to increasing traffic congestion. With more and more people owning two-wheelers (with increasing car ownership), the performance of street based public transport has been deteriorating and new off-road systems are needed at the earliest. A metro system is under construction but long construction periods and very high costs would restrict its reach to within city limits.

2.4 Housing

Housing is costly and unaffordable for the lower and middle classes. It is difficult for cities to keep adding spaces or zones within city limits exclusively for moderately priced housing, especially when migration across all income brackets has been ongoing & continues without halt. Low-priced housing in the suburbs would be an option if there is a means for workers to reach the city for employment efficiently and quickly – this can improve productivity and services.

2.5 Impact on growth and development

As of now, with high costs for housing and expensive / time consuming work journeys, the cost of labour for industry and businesses has been increasing. Since the economy of any city is dependent on availability of good quality labour at reasonable costs, the pressures on productivity at optimum costs for human capital have been

[3] Source - http://tejaswiblog.blogspot.com/2013/05/the-bangalore-traffic-handbook.html

© ASCE 2014

increasing. This may ultimately lead to flight of capital and hurt the region's economy.

2.6 Spreading growth beyond City Limits

In the longer term, very high growth rates within any city would become unsustainable and when a city experiences unusually high growth over long periods, city authorities must attempt to spread such growth out towards and even beyond suburbs to nearby towns. This can be greatly facilitated if cheap and quick travel options to the city core are made available. A suburban rail mass transit system can be developed at nominal cost (since tracks and estate already exist) and would offer the best solution to "spill over" some of the high decibel growth.

There is also the likelihood that satellite cities might start to become more attractive for migrants as job creation might take off in earnest even within these smaller cities bordering the city's metropolitan region. In the case of Bangalore, attempts to shift growth outwards have not been very successful in the past perhaps due to lack of good connectivity with passenger trains although there had been good road connectivity (this again was because there was no rail connectivity to speak of). However, since roads are currently overloaded, rail is the only option that provides for large capacity increases as and when needed.

3 SUBURBAN RAIL – THE MOST ECONOMC MASS TRANSIT SOLUTION

Due to increasing road congestion within the city, the government of the state of Karnataka had begun expanding roads initially whilst studying options of exclusive track guided rail systems (light rail or metro) for the longer term. An attempt was first made by involving the private sector for funding, but this failed to take off. Meanwhile, with severe restrictions on street width increases and road widening resulting in even more traffic chaos, construction of a state funded Metro rail system, named as 'Namma Metro' finally began in early-2007.

However, it was clear from the beginning that construction of the Metro rail system would take much longer than needed or anticipated whilst growth continued unabated. City planners also began to realize that the Metro system would not be able to meet the city's travel demands as and when they began operations.

In 2009, Praja-Raag (a city-based citizens group)[4] in association with CiSTUP[5], Bangalore, began studying various options in the context of the city's needs and requirements specifically with reference to cost implications, periods for construction and sustainability. The group chose Suburban Rail as the best option and in 2010, began a campaign to popularize it and approached planners and leaders with a proposal – 'Bengaluru Commuter Rail Service – Call to Action Report'. The

[4] Praja-RAAG (Research, Analaysis and Advocacy Group), an online citizen's group, Bangalore.

[5] CiSTUP – Center For Infarstructure, Sustainable Transport and Urban Planning, Bangalore

© ASCE 2014

Suburban Rail option had previously been suggested in many urban transport studies but not with much conviction as such systems had not been very successful in other cities in the country. The result of Praja's campaign bore fruit in 2011 when the Karnataka state government engaged RITES (Rail India Technical & Engineering Services) and commissioned a full and detailed study for a Suburban Rail system for the entire Bangalore metropolitan region.

The RITES completed the study and submitted the report to Government of Karnataka in 2012. As of March-2014, the proposal is now pending with Indian Railways for concurrence on its participation. The important highlights of this report are as follows:

3.1 Bangalore Suburban Rail Service – The Proposal

Suburban trains are to connect the suburbs and satellite towns up to about 80 km from Bangalore city centre. The electric trains would be environment-friendly and include features for enabling carriage of bicycles and operate along routes where tracks already existed. Some doubling or quadrupling of tracks would be necessary for operation of trains at high frequencies. About 20 trains per day are planned between each origin-destination pair initially but this number may vary based on loads and requirements. This would help connecting Bangalore city centres with the surrounding towns of Mandya, Ramanagaram, Tumkur, Dodballapur, Chikballapur, Malur, Bangarpet and Hosur. The below given map describes the overall connectivity being attempted through Suburban Rail services.

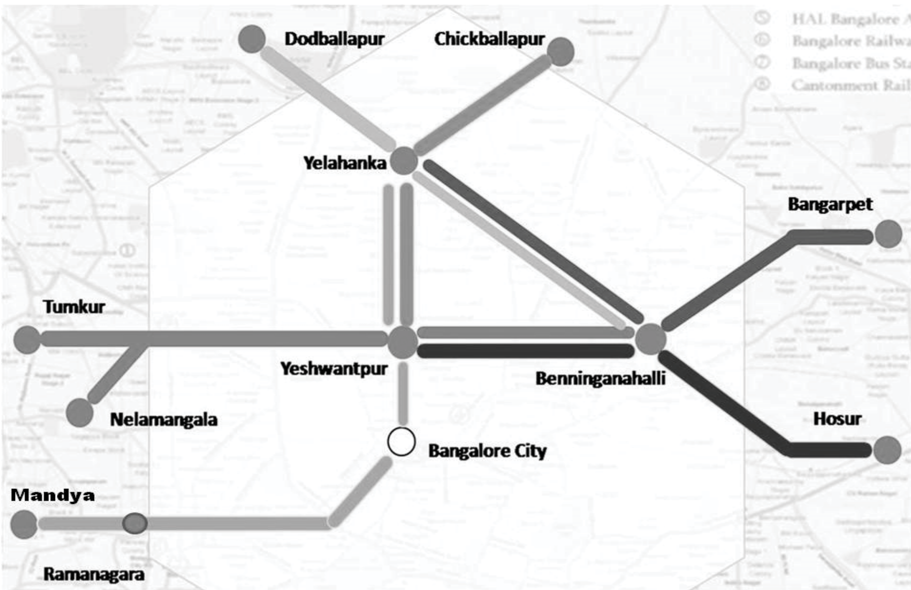


Figure 2 – Bangalore Suburban Rail Service Network

3.2 Proposed Routes

Six routes are planned as listed below to enable least changeovers. Generally, only a single change is necessary to travel from any one location to any of the others.

© ASCE 2014

The system overlaps sufficiently with other planned modes of city transport (i.e. the Metro system under construction and street-based bus services). The suburban Rail system is likely to attract up to 30% of commuters within 5km catchment areas on either side of the railway lines[6] and has the potential to serve as a faster urban transit option (since station spacing would be higher than the Metro urban rail system).

Routes	Distance (Km)
Yeswantpur - Yelahanka - Devanahalli – Chickballapur	60
Benninganahalli - Thanisandra - Yelahanka – Doddballapur	37
Yeswantpur - Benninganahalli - Anekal – Hosur	66
Tumkur/Nelamangala - Yeswantpur – Benninganahalli	83
Yelahanka - Benninganahalli - Whitefield - Malur – Bangarpet	80
Yelahanka - Yeshwantpur - City - Kengeri – Ramanagara – Mandya	70

Table 1 – Proposed Routes for Bangalore Suburban Rail Service

3.3 Network Length

The system (when fully built) would cover about 440km and connect most outlying suburbs and towns. Thus it has been estimated that investments on the system would pay off eventually over the years due to its reach and coverage.

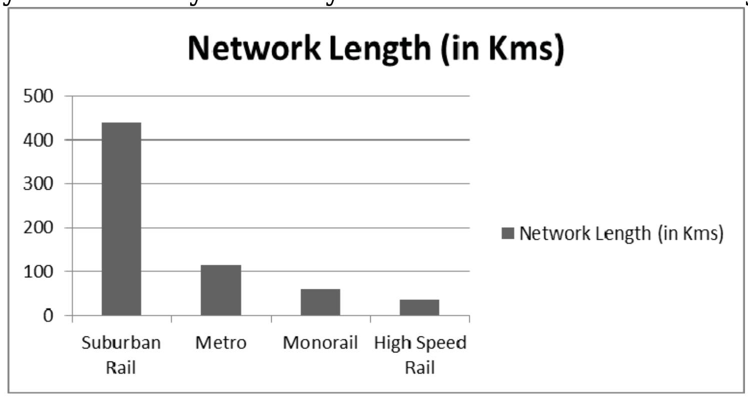


Figure 2 – Network length of different mass transit systems

3.4 Cost of building Suburban Rail System for Bangalore

As per RITES study report, costs for building suburban rail would be in the range of Rs.80-90 billion, which is approximately US$ 1.3 billion. Though this is substantial, it is far lesser than the costs for building other exclusive track mass transit systems.

	Suburban Rail	Metro System	Monorail	High Speed Rail
Length (Kms)	440	115	60	35

[6]2012 RITES Report on 'Implementing Commuter Rail Service in Bangalore'

© ASCE 2014

Total Cost (US$)	1.3 Billion	6.3 Billion	1.4 Billion	1.0 Billion
Construction Cost (Per KM - US$)	2.5-3.3 Million	33 – 66 Million	25 Million	30-35 Million

Table 2 – Comparison of Construction Costs for planned systems

3.5 Short Implementation Period

Another benefit of the Suburban Rail system is that it has the shortest time required for construction when compared with exclusive track systems like Metro Rail. Since the bulk of railway infrastructure already exists, all that is required is to augment tracks, signalling and platforms as necessary to enhance operational capacities without the need for acquiring large land parcels, building bridges, etc. Although the RITES report recommends implementation in multiple phases, it suggests commencement with 24 initial services within 6-9 months. Such a short time span for commencement is possible since most rail infrastructure already exists. Cost for commencing these initial services is pegged at about 180 Million Rupees (US$ 30 Million)[7].

This is a significant advantage that Suburban rail has over any other mass transit system for any city.

4 THE PROMISE OF SUBURBAN RAIL – SUSTAINABLE GROWTH BEYOND CITY

If viewed beyond urban transit issues, a suburban rail system can provide a city like Bangalore with the necessary means to address sustainable growth and development challenges. Suburban rail would not only address urban transit issues but also help the city to cope with infrastructure issues. Here is a snapshot of what it promises.

4.1 Moving growth beyond Bangalore

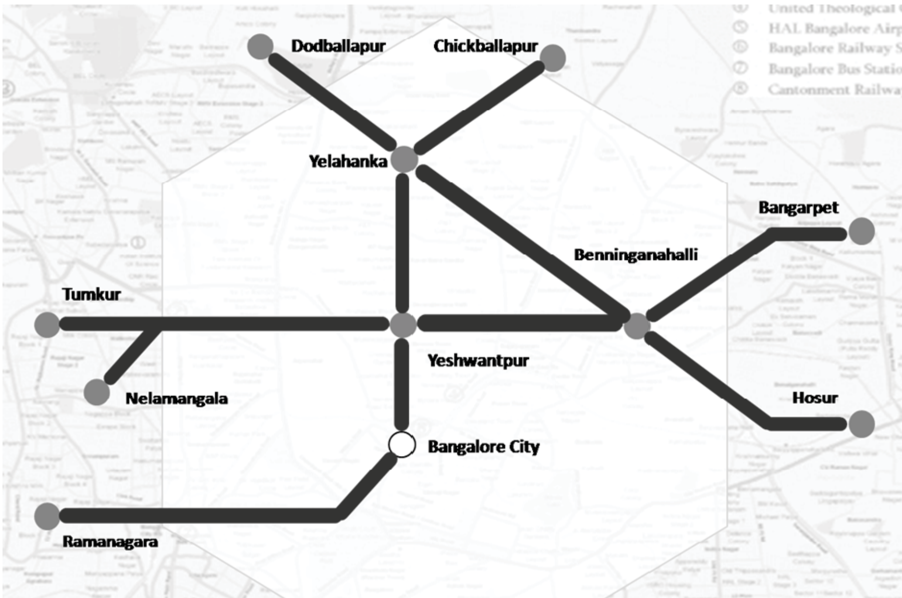
Connectivity to the nearby towns (Ramanagaram, Tumkur, Doddaballpur, Chikballpur, Hosur and Bangarpet) would throw open up huge opportunities in these satellite towns. In short, the acute land scarcity within the city would eventually be balanced by development in far flung suburbs and satellite towns.

- More rapid development of real estate and housing;
- Faster development of industries and businesses;
- Much quicker job creation;
- Development of social infrastructure such as schools, entertainment and health care;
- Large open spaces for setting up research and sports related infrastructure.

[7] 2012 RITES Report on 'Implementing Commuter Rail Service in Bangalore'

© ASCE 2014

4.2 The New Growth Centres



Picture 3 – New Growth Centers

Providing a Suburban Rail Service between city and these satellite cities would thus enable these towns to turn into "rapid growth centers" themselves. These growth centers already have rail connectivity with Bangalore but services presently are very few. The potential of these towns are significant because they are currently not very heavily populated despite their close proximity to Bangalore city. They have very large "headroom" for growth. The suburbs in between would also have potential to grow with rail connections.

Growth Centre	Distance from Bangalore	Population (approximate)	Catchment
Hosur	40 Kms	150,000	Anekal, Jigani, Electronic city
Ramanagaram	50 Kms	100,000	Kengeri, Bidadi
Tumkur	70 Kms	300,000	Nelamangala, Peenya, Jalahalli, Hessarghatta, Dobbspet
Chickballapur	70 Kms	70,000	Devanahalli, BIA, ITIR, DBP, avaiation hub
Dodballapur	40 Kms	90,000	Yelahanka, Dodballapur Indl Area
Bangarpet	70 Kms	150,000	Malur, KIADB

Table 3 – Growth Centers and Catchments[8]

[8] Source - 'Bengaluru Commuter Rail Service - Call to Action Report', Praja-RAAG, www.praja.in/nammarailu

© ASCE 2014

4.3 Housing

Since the cost of land in towns surrounding Bangalore is still very cheap compared to city, the poorer and low to middle income sections would find housing affordable in these towns. With Suburban rail, these towns would attract people who can commute to city on a daily basis for employment. Conversely, land being cheap, industry would also find it economical to shift or expand or even start new ventures in these towns due to the large pool of readily available employees and skilled labour from city or even across from the city. A trend would thus begin where people shift residences to towns with favourably priced housing depending on individual employment locations.

This would be a great benefit for the city in terms of maintaining competitiveness and balancing its growth across suburbs up to the satellite towns rather than confining growth within.

4.4 Environment and Public Health

Both, environment and public health are expected to improve with the introduction of Suburban rail services as would the efficiency in transporting people to and from the city with the anticipated reduction and control of vehicle emissions.

Increased Rail services would also make it possible to introduce control and traffic restraining measures such as congestion or cordon pricing for street based vehicles.

4.5 Local economies of satellite towns

Satellite towns nearby have different strengths (see table below) and pursue various economic activities. With Suburban rail, economic activities in these towns would become more vigorous as rail connections would get them 'closer' to markets.

Major Towns	Population	Major Trade/Economic activity
Mandya	137,735	Rice, Sugar, Silk Rearing, Higher Educational Institutes
Ramanagaram	79,365	Silk Rearing, Higher Educational Institutes
Malur	27,815	Clay tile-and-brick industry, Small-scale industries
Bangarpet	38703	Close to KGF's BEML, Mostly depends upon jobs in Bangalore
Hosur	84,394	Industrial Hub
Chikballapur	54,968	Flowers, Horticulture, Silk Rearing, Higher Education Institutes
Doddaballapur	71,606	Silk Weaving, Handlooms, Apparel Industrial Park
Tumkur	305,821	Produces rice, pulses, and oil seeds. Industrial hub producing coarse cotton cloths, blankets, ropes, etc.

Table 4 – Trade and economic backbone of towns[9]

[9] Population Source : From Indian Census Data of 2011

© ASCE 2014

5 CONCLUSION

Suburban Rail Service can be a game changer for metropolitan cities in emerging economies. The example of Bangalore has been used to detail how it could help immensely to mitigate urban transport issues besides assisting the nearby towns with growth and development. Expanding roads or building expensive roadways between the city and nearby towns would not address issues of air pollution or traffic congestion. Construction costs being low (when compared with new systems), Suburban Rail is probably the best option to connect satellite towns or twin cities within a metropolitan region owing to the many benefits that it promises.

6 ACKNOWLEDGEMENTS

This paper has been inspired by the outcome of relentless efforts of many individuals, entities, NGOs, Civil Society members and government officials in pursuing the proposal for Suburban Rail Services in Bangalore.

Special thanks to Smt. V. Manjula, Commissioner, Directorate of Urban Land Transport (DULT), Karnataka, for taking keen interest in the proposal and taking up the matter with higher authorities.

Thanks to Senior IAS officer Shri. V. Madhu, Former Principal Secretary IDD, Government of Karnataka, for his inspiration to take up this challenge under aegis of Praja banner.

Heartfelt thanks to the Ex-Member of Parliament from Tumkur, Mr. G. S. Basvaraj and Rajyasabha member, Prof. Rajeev Gowda for their continued support.

Thanks to all individuals and groups who have directly or indirectly supported the campaign in different capacities.

The campaign for Suburban Rail Services for Bangalore would not have been possible without online debates and discussion on the subject on Praja.in website.

7 REFERENCES

- *Census of India (http://www.censusindia.gov.in), Ministry of Home Affairs, Government of India*
- *RITES Ltd – Report on 'Implementation of Suburban rail Service in Bangalore', 2012.*
- *Bangalore Traffic police – Growth of Vehicles in Bangalore City*
- *Praja.in (www.praja.in) – Suburban rail Project Wiki, discussions & contributions from members, 2007-2010*

© ASCE 2014

- *Praja.in (www.praja.in) – "Call to Action Report – Bangalore Suburban rail Service", 2010.*
- *http://tejaswiblog.blogspot.com/2013/05/the-bangalore-traffic-handbook.html - Bangalore Traffic.*

© ASCE 2014

Infrastructure Resilience in the UK: An Overview of Current Approaches

Karen Lee Hansen, PhD, DBIA[1] and Brian S. Neale, CEng, FICE, FIStructE, HonFIDE[2]

[1]California State University, Departments of Civil Engineering and Construction Management, 6000 J Street, Sacramento, CA 95819-6029; PH (916) 278-6616; FAX (916) 278- 7957; email: hansenk@ecs.csus.edu

[2]United Kingdom Hazards Forum, 441 Chalfont Close, Appleton, Warrington, Cheshire WA4-5JT, United Kingdom: PH 44 (1925) 602015; email: brian.s.neale@virgin.com

ABSTRACT

Catastrophic experiences that receive worldwide publicity can include both "natural" and "human made" events. Examples include earthquakes, incidents in chemical plants, fires, tsunamis, explosions, and more, where each type of event can (and has) led to significant loss of life. No nation has been granted immunity from the effects of these types of events and the international community frequently pulls together to help where they feel they can. More frequently, however, such events can be less dramatic, but can have notable/severe consequences of another type – that is, economic. Learning for the future and, thus for future generations, is crucial.

The functioning of modern societies continues to be increasingly dependent on physical infrastructure. Civil engineering plays a critical role in delivering a diverse range of sustainable infrastructure systems, including building and industrial facilities, transportation, energy, water supply, waste management and communications systems. The profession also plays a critical role in maintaining the quality, integrity, and longevity of these systems.

Society has a right to expect infrastructure that functions well; yet without resilience, that infrastructure is increasingly vulnerable. Traditional approaches of reactive, corrective actions to slow, reduce and eliminate the impacts of catastrophic events, or prevent them altogether, in many cases have proven to be costly, inefficient, and ineffective. In response, a wide range of constituencies from both within and outside civil engineering has been attempting to define the attributes and characteristics of infrastructure resilience, particularly with integrated/enhanced sustainability features in mind.

To establish a direction, in 2011 the Central Government of the United Kingdom (UK) published a national infrastructure plan, which keeps infrastructure resilience under review. Emerging research in the UK indicates that decision-makers need to integrate resilience at all stages of the project life cycle, particularly the early

© ASCE 2014

funding allocation, planning and conceptual design phases. More specifically, to be successful in the pursuit of infrastructure resilience, civil engineers, as well as others in the Architecture, Engineering, and Construction (AEC) Industry, need to: (1) define, plan, and design for more resilience; (2) procure, construct, commission, operate, and maintain infrastructure with resilience in mind; and (3) supply more building technologies, systems, products and materials that embody resilience with enhanced sustainability in mind.

Topics such as sustainability, globalization, emerging technologies, innovation – and infrastructure resilience – benefit from being viewed in an international context. Multiple organizations within the international community have been formally, explicitly, and proactively addressing infrastructure resilience. In the UK, researchers have asked: What can be done? How can it be done? With what resources can it be done? This paper investigates current approaches to infrastructure resilience in the UK and proposes practical ideas to stimulate an on-going, industry-wide dialogue and debate. It will be of interest to civil engineers and to those in other disciplines in both professional practice and academia, as well as to infrastructure owners and managers.

INTRODUCTION

By no means is there a standard accepted definition of infrastructure resilience; however, most definitions contain three elements: 1) performance of a system under stress; 2) consequences of this stress and return to normalcy; and 3) scale and affordability of required response. Hudson *et al* of Arup UK (2012) define *resilience* in the following way:

> Resilience can be measured by the scale of challenge that the system can endure beyond normal demand, and in decision making, may be balanced against other factors by what is proportional, affordable and tolerable.

The authors also identify several other issues that are key is any discussion of resilience:

> ***Interconnectivity***. Resilience of any individual asset usually depends on services and external assets of other systems. Networks can both support and undermine resilience and can involve different functions within a shared whole, such as human resources, physical assets, information technology and communications, and business functions. By leading to indirect hazards, interconnectivity can be challenging for designers and subsequent managers alike. Please see Figure 1 – Wide Range of Potential Interconnected Hazards.

> ***Capacity***. Ideally, a system should operate efficiently under normal circumstances, while having resilience to exceptional events. But making greater efficiencies in systems may result in greater vulnerability and brittleness. When the operational life of assets is extended by requiring them

to carry greater loads, impacts can be felt widely. The effects of increasing loads on existing systems can be seen in the transportation, waste management, telecommunications, water resources, and power generation and distribution industries.

Diversity and Redundancy. Diversity and redundancy are similar concepts. Hudson *et al* (2012) offer: "…diversity is the ability to rely on any two or more dissimilar means to perform a function, whereas redundancy is inherent resistance by tolerating failure of individual components because sufficient remain to keep the system operating at an acceptable level. Diversity utilizes alternative means to achieve the same effect, whereas redundancy relies on duplication."

Ownership and governance. In the past fifty years, in the UK infrastructure has increasingly passed to private industry, which then operates and maintains this infrastructure. Private sector ownership brings with it the possibility of greater innovation and rapid modernization as well as the potential for poorly written procurement documents and cut corners. An ideal balance of private-public investment could insure optimization of infrastructure resilience consistency, control, efficiency, and momentum.

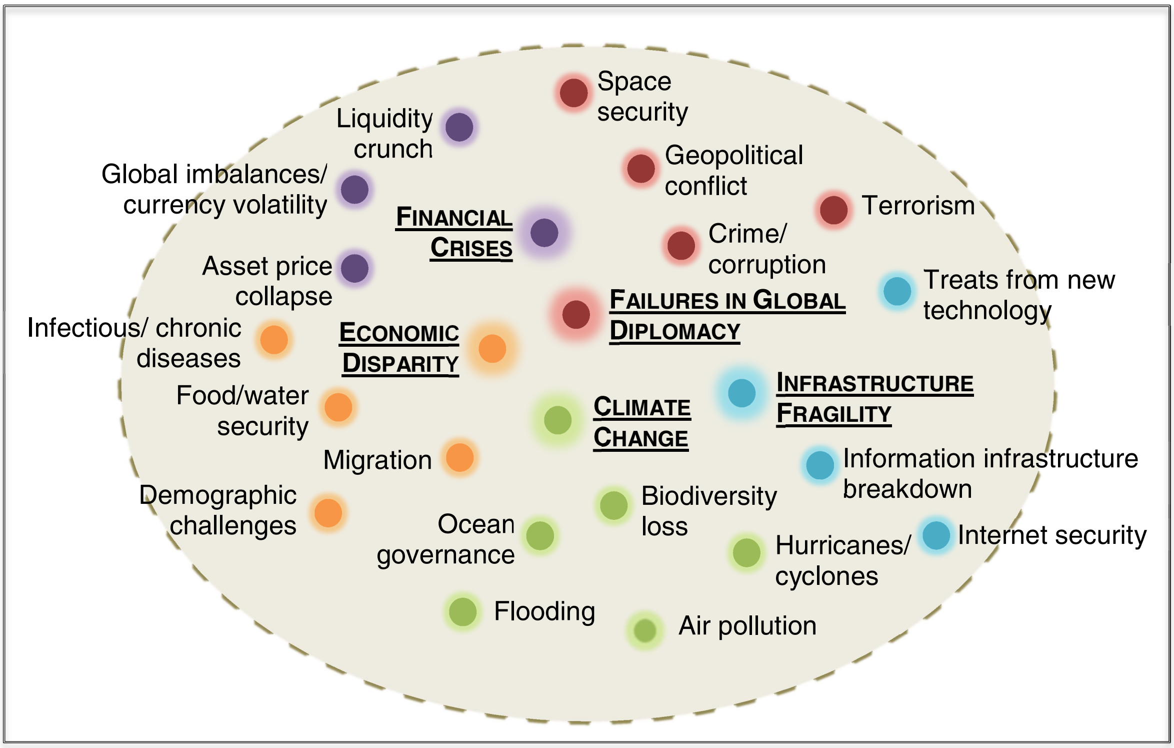


Figure 1 – Wide Range of Potential Interconnected Hazards
Adapted from: Hudson *et al*, 2012

© ASCE 2014

UK GOVERNMENT'S APPROACH

In many ways, the United Kingdom – an island nation with miles of coastline and the initiator of the Industrial Revolution – has unique challenges in addressing the need for infrastructure resilience. Victorian civil engineers left a legacy of now aging railroads, sewers, and reservoirs, and the nation depends on a highly complex and interconnected set of infrastructure systems. As is true for all industrialized nations, the UK depends on its infrastructure to sustain the well-being of its residents, economy, and political stability.

Following a review of the disastrous 2007 summer flooding, in 2009 the UK government worked with industry and regulators to initiate development of Sector Resilience Plans for each of nine infrastructure sectors: Communications; Emergency Services; Energy; Finance; Food; Government; Hazardous Sites; Health; Nuclear; Transport; and Water. Please see Table 1 for further detail.

Thus far, the government has produced four rounds of assessments, the most recent Sector Resilience Plans having been issued in November 2013. The Civil Contingencies Secretariat, based in the Cabinet Office (top executive authority in the UK), overseas the process of developing and distributing the plans. Due to their sensitive nature, the Sector Resilience Plans are classified, and only unclassified summary information is made public.

Table 1 – Infrastructure Sectors, Associated Sub-Sectors and Lead Government Departments

Sector	Sub-Sector(s)	Sector Resilience Lead
Communications	Broadcast	Department for Culture, Media, and Sport
	Postal	Department for Culture, Media, and Sport
	Telecoms	Department for Culture, Media, and Sport
Emergency Services	Ambulance	Department for Health
	Coastguard	Department for Transport
	Fire & Rescue	Department for Communities and Local Government
	Police	Home Office
Energy	Electricity	Department for Energy and Climate Change
	Gas	
	Oil	
Finance		HM Treasury
Food		Department for Environment, Food and Rural Affairs
Government		Cabinet Office
Hazardous Sites		Department for Business, Innovation and Skills
Health		Department for Health
Nuclear		Department for Energy and Climate Change
Transport	Aviation	Department for Transport
	Ports	Department for Transport
	Rail	Department for Transport
	Road	Department for Transport
Water		Department for Environment, Food and Rural Affairs

© ASCE 2014

Resistance: Concerns direct physical protection, e.g. the erection of flood defences.
Reliability: The capability of infrastructure to maintain operations under a range of conditions, e.g. electrical cabling is able to operate in extremes of heat and cold.
Redundancy: The adaptability of an asset or network, e.g. the installation of back–up data centres, and
Response and Recovery: An organisation's ability to respond to and recover from disruption.

Figure 2 – The components of infrastructure resilience
Source: Cabinet Office Summary of the 2013 Sector Resilience Plans

The UK government's approach to building infrastructure resilience is based on the principal components show in Figure 2. The government urges infrastructure owners to work with the government and regulators to produce economical and proportionate strategies that recognize legal frameworks, industry standards, license agreements, and business models. The government believes that results will benefit from improved information flow and increased collaboration among participants.

Like other industrialized nations, the UK has integrated assets over the past decade in search of greater efficiencies; however, these activities have led to the creation of systems that have unknown interdependencies and, consequently, unknown vulnerabilities. Additionally, the extensive imbedding of information technology for monitoring and control purposes has contributed further to infrastructure vulnerability. Please see Figure 3 for some of the high consequence risks facing the United Kingdom.

James Stewart, Chairman of KPMG's Global Infrastructure Practice and former Chief Executive of Infrastructure UK, has noted (Hall, 2013):

> I get the impression that decision makers don't always understand the cost vs. benefit ratio of investing in greater resilience at a system level. They are fairly clear on why they don't want a bridge to collapse or a power plant to fail, but they are less clear about the costs and risks of systemic failure.
>
> In a time when governments are dealing with constrained capital budgets and where the first question is always 'how much is this going to cost?', it's going to become increasingly difficult to get investors – government or otherwise – to pay for mitigating systemic risk.

© ASCE 2014

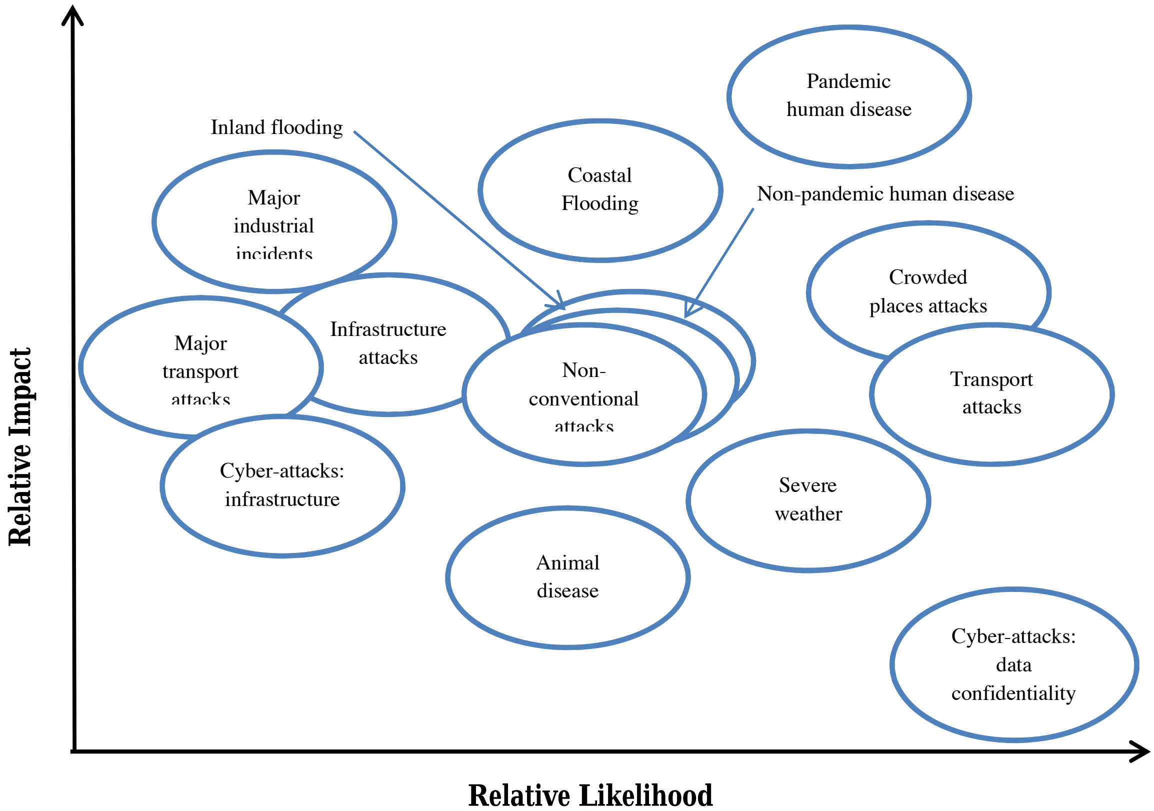


Figure 3 – High consequence risks facing the United Kingdom
Source: Cabinet Office, *Keeping the Country Running*

Table 2 offers an approach for understanding the dimensions of infrastructure's interdependencies.

AN INFRASTRUCTURE RESILIENCE DESIGN FRAMEWORK

Several authors (Hudson *et al* and Montgomery *et al*, 2012) suggest the necessity for a cycle of infrastructure resilience assessment. These frameworks provide a starting point for an analysis of a single system or can be scaled up to depict systems with multiple interactions. For policy makers, the frameworks provide a logical response to the need to provide infrastructure resilience.

Table 2 – Dimensions of Infrastructure Interdependence
Adapted from Rinaldi et al, 2001

State of operation	Type of failure	Types of interdependencies	Environment	Response behavior/coupling
Repair/restoration	Common Cause	Geographic	Health/safety	Adaptive
Normal	Cascading	Logical	Social/political	Loose–tight
Stressed/disrupted	Escalating	Cyber	Security	Inflexible
		Physical	Technical	Linear–complex
			Legal/regulatory	
			Public policy	
			Business/economic	

© ASCE 2014

The framework defined by Hudson *et al* involves a process with four stages:

Identified. risk ownership, profile, and tolerance are identified

Assessed. likelihood, severity, and impact of risk are assessed

Addressed. risk is eliminated reduced, isolated, and/or controlled

Reviewed. process and results are reviewed, modified, and reassessed as necessary

Risks can be identified by the client, operators, and users. Extent of stakeholders' ability to tolerate failure of the system must be established. Ways of identifying potential risks include:

- studying past events where were similar to the current design under consideration
- considering hazards that exceed historical levels and that go beyond the basis of design
- building "what-if" scenarios where compounded or indirect hazards that do not have historical precedents
- scanning the horizon for possible future hazards, such as technological, environmental, and/or geopolitical change

When the risk is identified, then its severity and impact can be assessed by either qualitative or quantitative means, depending on the information available. Several techniques include (Hudson *et al*):

- hazard operability study, frequently used in chemical processing plants – components, performance parameters, and deviations are comprehensively defined
- single point failure evaluation, applied in mechanical, electrical, and process plants – allows critical points to be rectified and corrected
- event-tree or fault-tree analysis, used when a sequence of events leads to failure – combinations of faults, usually in diverse or redundant systems, which can produce a system failure are evaluated

Following identification and assessment, intolerable risks should be addressed. Risks rarely can be eliminated completely, but they can be reduced. As the risk evaluation process proceeds, design strategy may need to be reassessed and possibly broadened in scope. The range of design solutions will vary depending on the challenge being faced. Lack of resilience on one level can be countered through redundancy or diversity of others systems.

© ASCE 2014

When risks cannot be removed or mitigated through design, then a response to system failure should be identified. Responses to foreseeable failure can be planned and practiced, and organizational procedures for dealing with unknown risks should be developed.

ACADEMIC AND INSTITUTIONAL RESPONSES

Designers and policy-makers alike need robust tools they can use in developing and maintaining resilient infrastructure. A promising approach is being fostered by investigators at Oxford University's Infrastructure Transitions Research Consortium (ITRC). They are developing an integrated system-of-systems model that is designed to simulate the long term performance of infrastructure networks in the United Kingdom. The model can be used to compare various infrastructure provisions to be implemented over the coming decades. A wide range of scenarios involving future demographic variations, economic growth, and climate change can be used to evaluate actions.

With the participation of several other universities (Cardiff University, Newcastle University, the University of Cambridge, the University of the Leeds, the University of Southampton, and the University of Sussex) and engineering institutions (Institution of Civil Engineers, Institution of Engineering and Technology, and Institution of Mechanical Engineers), as well as government departments and agencies, ITRC has based its analysis on four alternative strategy portfolios:

Minimum intervention, which reflects historical levels of investment, maintenance, and incremental change;

Long term capacity expansion, which focuses on large scale, long-term investment in physical capacity to meet increasing demand;

Increasing system efficiency*,* which focusses on a range technological and policy interventions to increase efficiency of current infrastructure; and

New services and planning*,* which focusses on restructuring the current mode of infrastructure service.

The ITRC is providing data to assist political, economic, and societal choices. The goal is to explore the implications of these choices in the long term, acknowledging multiple interdependencies and uncertainties.

In June 2014, the Institution of Civil Engineers (ICE) issued its *State of the Nation: Infrastructure 2014* report. The highly anticipated report reflected and amplified the work being done by the Oxford team. Among the report's recommendations are three strategic criteria:

© ASCE 2014

1. Infrastructure UK (within HM Treasury) should expand the existing criteria used as a basis for making decisions on priority infrastructure projects to reflect major future challenges – criteria should include resilience, availability, the pathway to a low carbon economy and better acknowledge interdependencies across networks.

2. Government and private providers of infrastructure should be prepared to make tough choices regarding the levels of resilience in the UK's infrastructure networks. This will require an assessment of costs and the management of public expectation regarding availability.

3. Government should provide more clarity, certainty and transparency for potential investors through the regularly published National Infrastructure Plan project pipeline by including detail on investable projects, their status, planning approval, ownership structure and revenue streams.

ICE's *State of the Nation: Infrastructure 2014* report points out that the 2013/14 winter flooding showed that the UK government ultimately "bears the risk for major, unplanned interruptions in infrastructure networks and the resulting impact on society and the economy." These unfortunate events resulted in greater political attention on infrastructure's contribution to the economy and its transformative powers. However, the report concludes that not enough has been done to address the important issue of resilience or the constraints on the provision and maintenance of the UK's infrastructure networks.

ICE's findings also indicate that: "three sectors – energy, flood management and local transport – are of particular concern. A narrowing gap between capacity to supply energy and demand; inadequate resilience to flooding, and the decline in maintenance of local roads and flooding assets due to investment cuts have all contributed to the current grades [C-, C-, and D-, respectively]. ICE's overall conclusion is that in order to compete in the global economy, the UK's approach to delivering and maintaining infrastructure requires attention.

CONCLUSION

Infrastructure resilience necessitates a multi-disciplinary approach because hazards usually do not recognize well-defined professional boundaries. Societal objectives for infrastructure resilience align very closely with those for infrastructure sustainability. Designing for infrastructure resilience is both proactive and reactive, and above all adaptive. Increasingly extreme environmental events have highlighted where infrastructure resilience is weak or lacking. Such events also have raised awareness and increased incentives for reducing their impacts. Civil engineers currently are well-positioned to help mitigate damage to infrastructure by applying lessons learned and by participating in long-term planning that will afford long-term gains.

© ASCE 2014

REFERENCES

Ainger, Charles and Fenner, Richard. (2014). *Sustainable Infrastructure: Principles into Practice*. ICE Publishing, Thomas Telford Ltd, London.

Cabinet Office. (2011). *Keeping the Country Running: Natural Hazards and Infrastructure – A guide to improving the resilience of critical infrastructure and essential services*. UK government.

Cabinet Office. (2013). *2013 Sector Resilience Plans*. UK government.

Guthrie, Peter and Konaris, Thalia. (2012) *Infrastructure and Resilience*. Foresight, Government Office for Science, Commissioned Review.

Hall, J.W. (2013). "Systems failure: Avoiding the unthinkable." *INSIGHT – The global infrastructure magazine,* Issue No. 5. Special issue on resilience. KPMG, UK.

Hudson, Stephen *et al*. (2012). "Engineering resilient infrastructure," *ICE Civil Engineering Special Issue: Infrastructure Resilience*. Institution of Civil Engineers (ICE), Volume 163, Issue CE6, November 2012. Pages 5 – 12.

Infrastructure Transitions Research Consortium (ITRC). (2014). *National infrastructure assessment: Analysis of options for infrastructure provision in Great Britain*. Interim Results, January 2014.

Institution of Civil Engineers. (2014). *The State of the Nation: Infrastructure 2014*. ICE, London, UK.

Montgomery *et al*. (2012). "An innovative approach for improving infrastructure resilience," *ICE Civil Engineering Special Issue: Infrastructure Resilience*. Institution of Civil Engineers (ICE), Volume 163, Issue CE6, November 2012. Pages 27 – 32.

Neale, Brian S., ed. (2012). *ICE Civil Engineering Special Issue: Infrastructure Resilience*. Institution of Civil Engineers (ICE), Volume 163, Issue CE6, November 2012.

Rinaldi, B.S.M., Peerenboom, J.P., and Kelly, T.K. (2001). "Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies." IEEE Control Systems Magazine. Pages 11 – 25.

© ASCE 2014

Working with the Mississippi River for Sustainable Storm Protection

Russ J. Joffrion, PE[1], David S. Eley, PE[2] and Blake E. Cotton, PE[3]

[1]Louisiana Coastal Protection and Restoration Authority, 450 Laurel Street, 11th Floor, Baton Rouge, Louisiana 70801; PH (225) 342-6850; FAX (225) 342-6801; email: russ.joffrion@la.gov
[2]GeoEngineers, Inc., 11955 Lakeland Park Boulevard, Suite 100, Baton Rouge, Louisiana 70809; PH (225) 293-2460; FAX (225) 293-2463; email: deley@geoengineers.com
[3]GeoEngineers, Inc., 11955 Lakeland Park Boulevard, Suite 100, Baton Rouge, Louisiana 70809; PH (225) 293-2460; FAX (225) 293-2463; email: bcotton@geoengineers.com

ABSTRACT

The Louisiana coast is losing land at an alarming rate. This land loss has resulted in greater damage to infrastructure near the coast, as land and marsh that historically buffered this infrastructure disappears. Infrastructure in Louisiana is critical to the United States for shipping along the Mississippi River, and for oil and gas production and import/export. Land loss in Louisiana is the result of years of well-intentioned, but unsustainable, practices. Louisiana is in the initial stages of a 50-year plan (Louisiana's Comprehensive Master Plan for a Sustainable Coast, 2012) to build resilient infrastructure that will work with the natural delta and coastal processes to provide long-term, sustainable coastal protection for the State. Given the projected annualized cost of doing nothing, Louisiana can't afford not to implement the Plan.

THE CHALLENGE

In Louisiana, Hurricanes Katrina and Rita in 2005 and Gustav in 2008 caused loss of life, damage to property and infrastructure, and economic losses as a result of closed ports, industries, and businesses. The Mississippi River Louisiana delta is losing land at an alarming rate that, if unabated, will require relocating communities, will damage energy infrastructure resulting in increased energy costs, and will result in progressively more expensive storm response costs (Estimated $7.7 billion to $23.4 billion annualized cost without any action in 50 years as shown in Figure 1). Aside from issues related to sea level rise, these recent storms are having a more disastrous effect due to years of well-intentioned, but unsustainable practices. Louisiana is in the initial stages of building resilient infrastructure that will work with

© ASCE 2014

the natural delta and coastal processes to provide long-term, sustainable coastal protection for the State.

Louisiana has lost 1,880 square miles of land since the 1930s. If nothing is done to reverse this trend, Louisiana has the potential to lose up to an additional 1,750 square miles of land over the next 50 years as shown in Figure 2. This loss will increase flooding risk with disastrous effects.

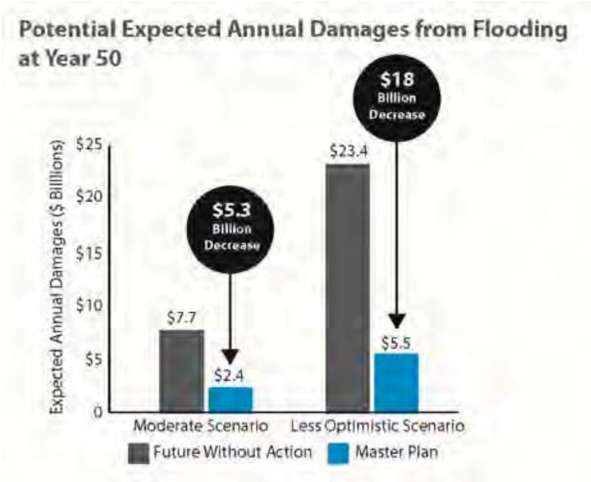


Figure 1. Source – Louisiana's Comprehensive Master Plan for a Sustainable Coast, 2012.

HOW DID WE GET HERE?

As the Mississippi River has been leveed and armored to prevent natural meandering and flooding, and other control structures upstream have captured sediment that historically was transported down the river, the delta's ability to replenish itself has been diminished.

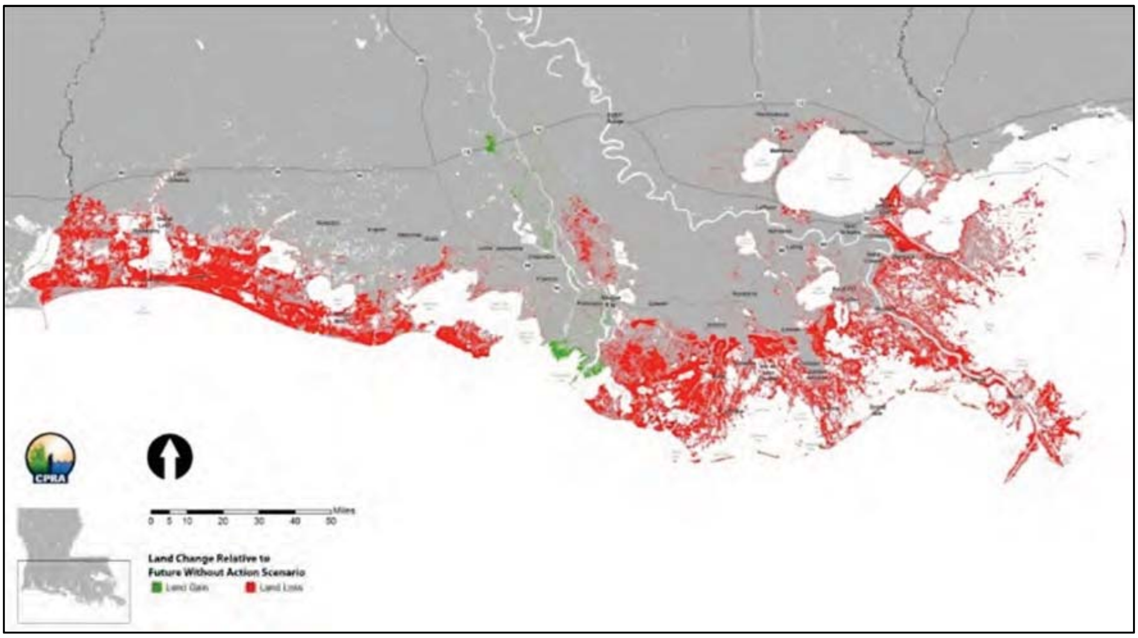
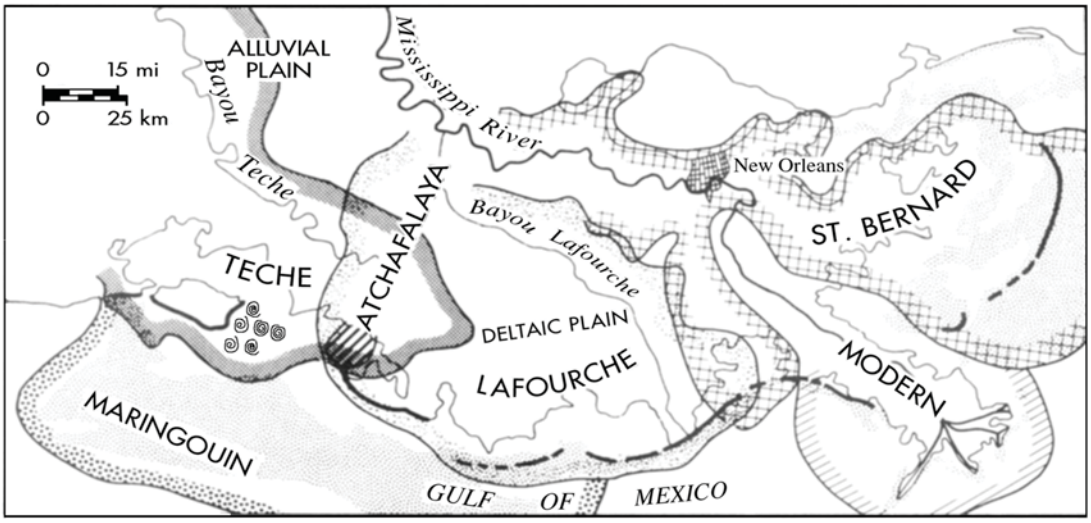


Figure 2. Source – Louisiana's Comprehensive Master Plan for a Sustainable Coast, 2012.

© ASCE 2014



KEY
Shell Reef
Barrier Shoreline
Sand

DELTA COMPLEX	AGE (YEARS BP)
Maringouin	7250-6200
Teche	5700-3900
St. Bernard	4600-1800
Lafourche	3500-400
Modern	Active
Atchafalaya	Active

Figure 3. Source - Saving Louisiana's Coastal Wetlands, EPA Report #230-02-87-026, April 1987.

The levee system along the Mississippi River and tributaries has been in place for hundreds of years. In 1717, the first levee along the Mississippi River was constructed in New Orleans. Upon completion, the levee was 3 feet high, 5,400 feet long and 18 feet wide at the top (http://www.mvd.usace.army.mil/About/MississippiRiverCommission(MRC)/History.aspx). Initially in the interest of stabilizing the Mississippi River for commerce, and later for flood control, river levee, revetment, and channel “improvements” have continued since development of the first levee. The same levees that provide protection and promoted development along the fertile Mississippi River Valley have significantly diminished the ability of the Mississippi River Delta to replenish itself. The delta building process is also affected by upstream reservoirs and flood control projects, resulting in the Mississippi River carrying about 60 percent less sediment than in the 1950s (Secretary of the Interior, March 1994). Natural flooding cycles that provided sediment and nutrients to the delta, and geomorphologic shifts in the river channel location within the delta (Figure 3) have been controlled by the levee system. If the river were allowed to follow its desired path today, the main channel would likely shift approximately 130 miles to the west following the Atchafalaya River channel. This shift is prevented by a large gate structure (the Old River Control Structure) that regulates the amount of water flow to the Atchafalaya River from the Mississippi River.

© ASCE 2014

In addition to existing Mississippi River and Tributary infrastructure, there are other features and land forms which also affect Louisiana's working coast. Canals exist both for both navigation and oil and gas exploration. The USACE Intracoastal Waterway connecting New Orleans to Texas was completed in 1934, but portions existed in the early 1900s. This waterway, and many associated smaller canals were used for transportation of salt, oil, rice, sugar, coal, molasses, lumber, and general merchandise (Alperin, Lynn M., January 1983). The USACE Mississippi River Gulf Outlet canal (dredged in 1963 and closed in 2009) was a 76-mile "short-cut" navigation canal from the Port of New Orleans to the Gulf of Mexico. Many canals are attributed to the oil and gas industry for exploration and access to well heads in existing developed well fields (Saving Louisiana's Coastal Wetlands, April 1987).

Land loss in coastal Louisiana is significant and visible. Photographs of the Wonder Lake area near Montegut, Louisiana from 1990 and 2012 are shown in Figure 4. Canals, roads, levees, distributary ridges, and pipelines are typical land features and can be seen below in Figure 4. As marsh deteriorates due to a lack of nutrients, there are larger stretches of open water, which causes larger wind-driven wave erosion and an increase in the volume of tidal zone water flow (increasing currents and salt/fresh water movement). The result is that land loss rates increase more rapidly with time.

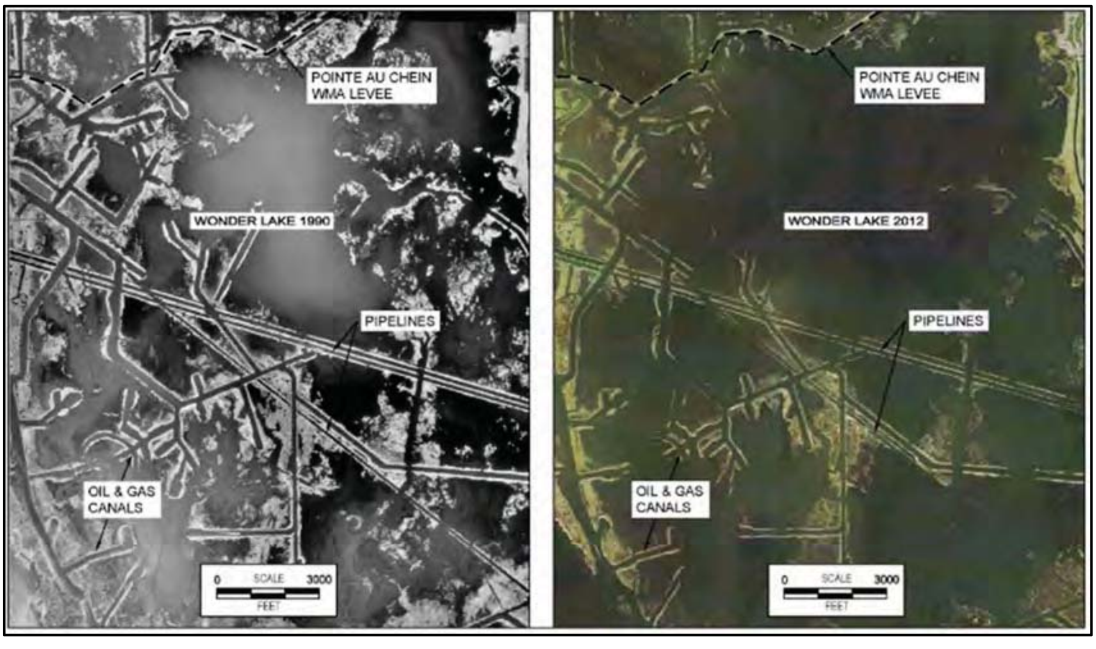


Figure 4. Aerial imagery from Google Earth, 1990 and 2012, Montegut, LA.

Louisiana's current coastal land loss problems and corresponding increased susceptibility to storm damage is the result of years of well-intentioned flood protection, navigation, and other improvements that have severely limited the ability of the delta to sustain itself. The full consequences of these actions are now evident and Louisiana has developed a Comprehensive Master Plan for a Sustainable Coast to restore some of the natural processes that will help restore the Louisiana coast.

© ASCE 2014

WHAT IS THE LONG-TERM SOLUTION?

In May of 2012, Louisiana developed the Coastal Master Plan for a Sustainable Coast which focuses on reducing risk of flooding from hurricane surge and waves. There were five objectives established for the plan.

1. Flood Protection - Reduce economic losses from storm-based flooding.
2. Natural Processes - Promote a sustainable ecosystem by harnessing the processes of the natural system.
3. Coastal Habitats - Provide habitats suitable to support an array of commercial and recreational activities coast wide.
4. Cultural Heritage - Sustain Louisiana's unique heritage and culture.
5. Working Coast - Support regionally and nationally important businesses and industries.

The plan does not include measures to protect against river flooding or measures to protect life and limb. The plan's protection measures were developed using the assumption that people must leave affected areas if human life is to be protected during a severe storm.

Louisiana's Comprehensive Master Plan used two primary factors to select projects: 1) how well did the projects reduce flood risk; and 2) how well did the projects build new land or sustain the land we already have?

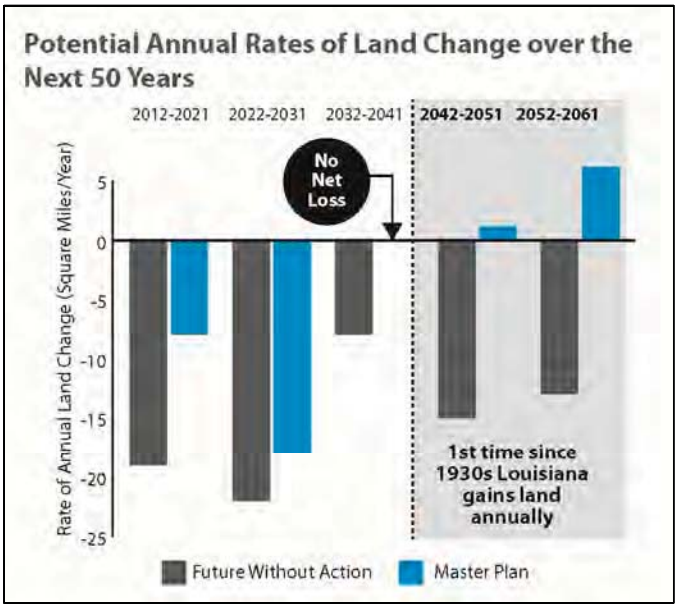


Figure 5. Source – Louisiana's Comprehensive Master Plan for a Sustainable Coast, 2012.

Using these priorities, the estimated $50 billion in projects proposed in the Master Plan is projected to reverse land loss and produce a net gain in land within the next 50 years (Figure 5).

The 2012 Comprehensive Master Plan combines a variety of projects to provide comprehensive protection for coastal infrastructure. The Master Plan expands beyond traditional infrastructure projects, such as levees, floodwalls, floodgates, rock dikes and pumps, or options such as elevating/flood-proofing buildings and relocation, and looks at sustainable natural processes for flood protection and land building. This comprehensive approach, expands beyond traditional approaches, and is driven by the requirement that projects build new land or sustain existing land. Projects in this sustainable category include barrier island restoration, marsh creation, water flow control, oyster barrier reefs, natural ridge restoration, and utilizing

© ASCE 2014

sediments carried in the Mississippi River (through dredging and constructed river sediment diversions) to provide fresh water, nutrients, and sediment to nourish existing islands/marshes and build new land/marshes. This is a different way of approaching flood protection that works with the natural storm surge buffers to improve and restore them in a manner that still preserves development, navigation, industry and seafood, but also preserves and builds the natural barriers/buffers that substantially reduce the cost of traditional "hard" flood protection infrastructure projects. In many cases these sustainable projects are restoring natural processes that have been interrupted by levees and channeling of the river.

Coastal Louisiana is a dynamic environment that is constantly changing and the current fisheries habitat status is not stable, unless action is taken to restore the natural processes that historically maintained the delta. The Master Plan utilizes these natural processes in a sustainable manner that provides storm protection benefit by preserving or building land while also preserving Louisiana's productive working coast and culture.

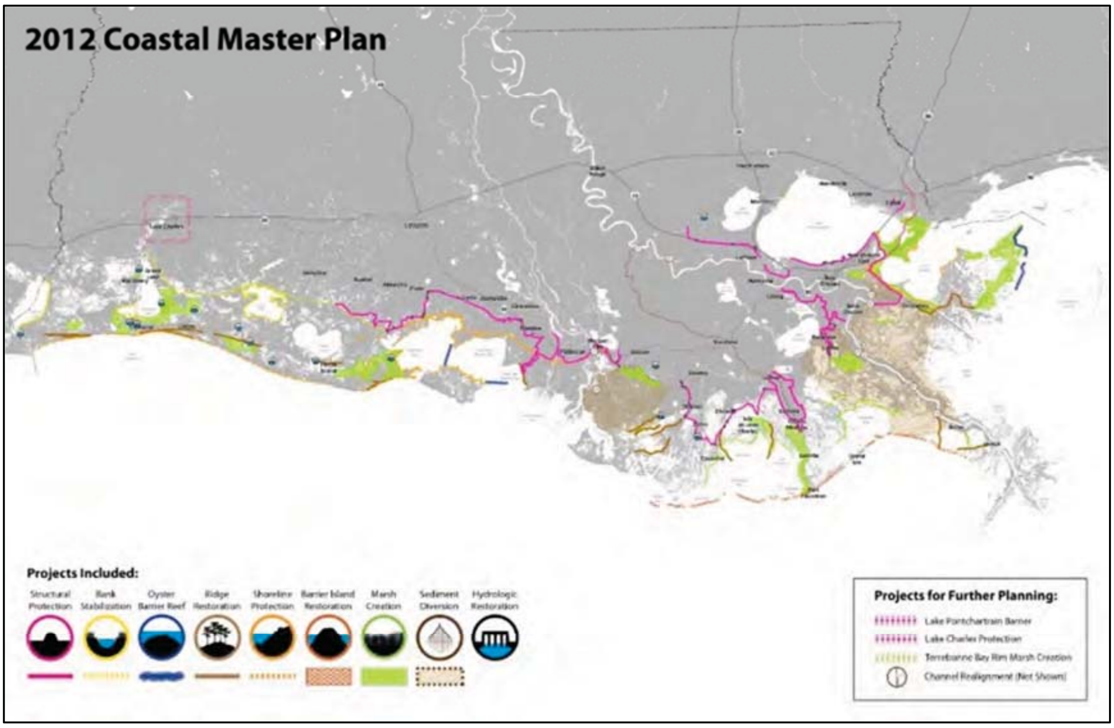


Figure 6. Master Plan Projects - Source - Louisiana's Comprehensive Master Plan for a Sustainable Coast, 2012.

PROJECT DISTRIBUTION

The 2012 Coastal Master Plan was developed through a ground breaking technical effort and extensive public outreach. Over 1,500 projects were identified for consideration in the Master Plan, and of these, 400 were objectively considered for the plan. The final plan recommends the 109 projects shown in Figure 6 to substantially increase protection for communities and make great strides toward

© ASCE 2014

achieving a sustainable coast. The projects include a diverse mix throughout the coast, from the Chenier Plain to the Mississippi border.

Figures 7 and 8 show the estimated cost by project type, and corresponding long-term land building potential compared to estimated cost. As can be seen, marsh creation and sediment diversion projects offer the greatest benefit in terms of long term land building. While marsh creation projects required a large portion of the plan's estimated cost, it is predicted that these type projects are not as effective for long-term land building as sediment diversion projects. Sediment diversion projects have a much higher potential to provide long-term land building for the coast when compared to the project cost.

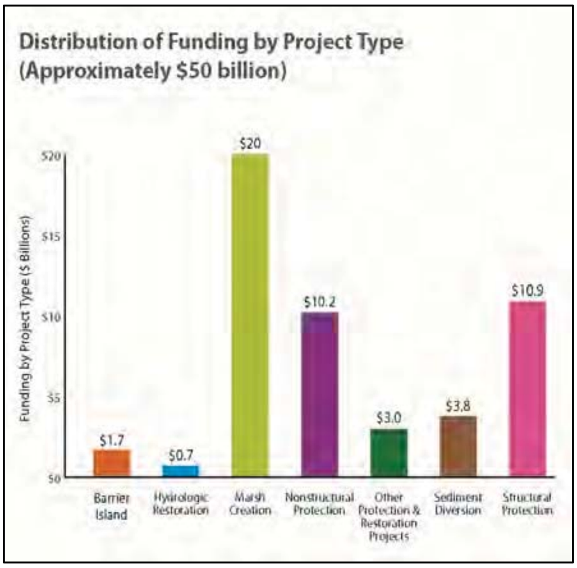


Figure 7. Source – Louisiana's Comprehensive Master Plan for a Sustainable Coast, 2012.

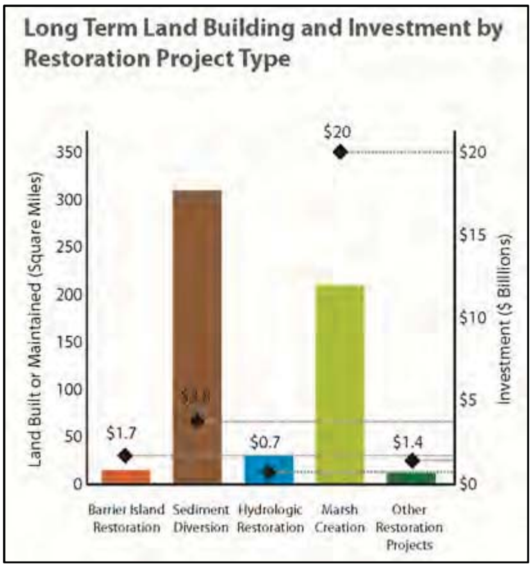


Figure 8. Source – Louisiana's Comprehensive Master Plan for a Sustainable Coast, 2012.

IMPLEMENTING AND MONITORING THE PLAN

The State of Louisiana and its partners are working to secure funding needed to implement the Master Plan. Funding for projects completed and in process has primarily come from the 1990 Coastal Wetlands Planning, Protection, and Restoration Act (CWPRA), often referred to as the "Breaux Act", the Coastal Impact Assistance Program (CIAP), Community Development Block Grants (CDBG), Hurricane and Storm Damage Risk Reduction System (HSDRRS), Water Resources Development Act (WRDA), and fines from the BP oil spill.

The Master Plan must adapt as more is learned about our dynamic coast and the effectiveness of projects. The Louisiana Legislature requires that the Master Plan be updated every five years with the latest science and technical information, so that the plan adapts over time to the dynamic coast environment and reflects knowledge gained with experience from implemented projects. The Master Plan will be updated next in 2017.

© ASCE 2014

Projects funded by CWPPRA require monitoring and evaluation of project effectiveness, and there is also a need to assess the cumulative effects of all projects to achieve a sustainable coastal environment. In 2003, Louisiana and the U.S. Geological Survey (USGS) received approval to implement the Coast-wide Reference Monitoring System (CRMS) as a mechanism to monitor and evaluate the effectiveness of projects at the project, region, and coast-wide levels. The CRMS design implements a multiple reference approach by using aspects of hydrogeomorphic functional assessments and probabilistic sampling (U.S. Geological Survey Fact Sheet 2010-3018; http://pubs.usgs.gov/fs/2010/3018/). The CRMS program is as dynamic as the coastal habitats it monitors.

PROJECTS

The 2012 Master Plan is the most current version of an evolving effort to restore the Louisiana coast. Since 2007, Louisiana has started design and/or construction of over 150 projects and is continuing with project design and construction as well as completing project planning and preliminary project engineering and design to make as many projects as possible "shovel-ready". Some sample projects are described below.

Figure 9. Schofield Island before and near construction completion. Images courtesy of Coastal Engineering Consultants, Inc.

Riverine Sand Mining/Scofield Island Restoration (BA-40): This project is located 20-plus miles south of Empire, Louisiana in Plaquemines Parish. The goals of this barrier island restoration project were to repair breaches and tidal inlets in the shoreline, reinforce the existing shoreline with sand, and increase the island width with back barrier marsh creation to increase longevity. The design approach was to maximize surface area habitat remaining after 20 years by reducing shoreline breaching through the introduction of Mississippi River sand via a dredge slurry pipeline approximately 22 miles long. Nearby offshore fine sediment was dredged and utilized for the back barrier marsh platform. The beach and dune elements were constructed to elevations of +4.0 and +6.0 feet North American Vertical Datum of 1988 (NAVD88), along 12,700 feet of shoreline. The marsh cells were constructed to

© ASCE 2014

a target marsh elevation of +3.0 feet NAVD88 with an average width of over 1,000 feet creating approximately 360 acres of future intertidal habitat. Before and during construction photographs are shown in Figure 9.

Lake Hermitage Marsh Creation (BA-42): The project area is located approximately 30 miles southeast of New Orleans, Louisiana in Plaquemines Parish. The collapse of the existing marsh and lake rim has led to increased tidal exchange and further interior marsh deterioration as shown in Figure 10. The goals of this project are to create approximately 600 acres of wetlands, reduce tidal exchange in marshes surrounding Lake Hermitage, and reduce fetch and turbidity to promote submerged aquatic vegetation. Several restoration techniques will be utilized to accomplish these goals. Sediment from the Mississippi River will be hydraulically dredged and pumped via pipeline to create approximately 600 acres of marsh in the project area. Approximately 25,000 linear feet of earthen terraces will also be constructed to reduce fetch and turbidity and promote submerged aquatic vegetation. In addition, approximately 6,000 linear feet of sand will be pumped along the eastern Lake Hermitage shoreline.

Figure 10. Lake Hermitage Project Area in 1998 (left) and 2012 (right)

Mississippi River Long Distance Sediment Pipeline(BA-43EB)/Bayou Dupont Marsh and Ridge Creation Project (BA-48)(under construction): The project area is located approximately 20 miles southeast of New Orleans, LA in Plaquemines Parish as shown in Figure 11. The collapse of the existing marsh has led to increased tidal exchange and further interior marsh deterioration. The goal of the Long Distance Sediment Pipeline (LDSP) project is to establish a permanent corridor onto which dredged material could be placed along the corridor to facilitate marsh creation of the land bridge utilizing the renewable sediment from the Mississippi River. The project will create approximately 610 acres of marsh and 11,000 linear feet of earthen

© ASCE 2014

ridge and will provide a corridor for future use for long-distance sediment conveyance to wetland creation projects.

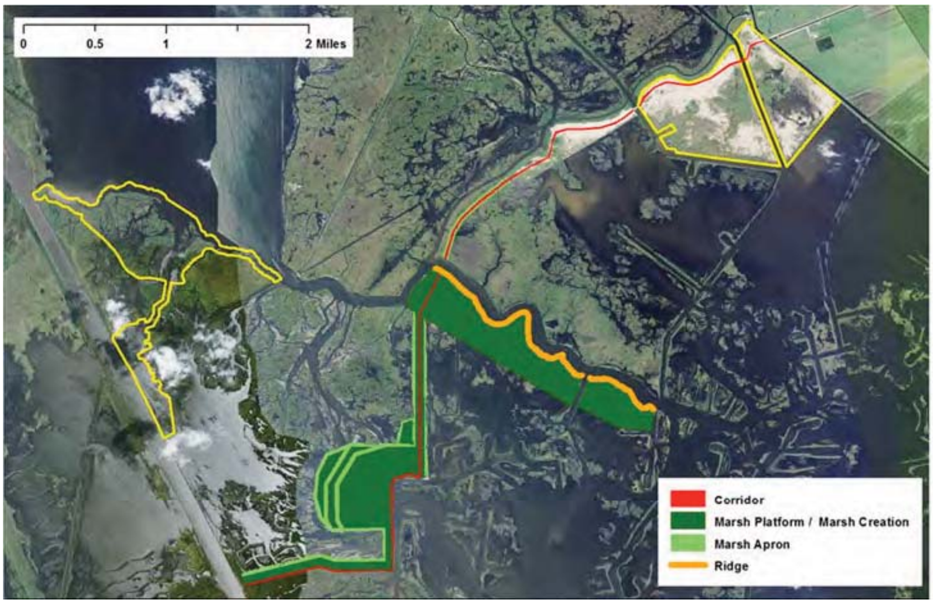


Figure 11. Long Distance Sediment Pipeline and Bayou Dupont Marsh and Ridge Creation Project

CLOSING

As shown previously, the projected annualized storm damage costs if no action is taken for both Louisiana the rest of the country make it clear that implementing the Master Plan for a Sustainable Coast is the logical and cost effective choice. Sustainability is critical to the long-term viability of the Plan and Louisiana's coast. Natural processes that balance land loss with gain are required, or traditional infrastructure will have to be continually upgraded with increased construction and maintenance costs. The Master Plan is Louisiana's evolving effort towards that end. For additional information, the Master Plan can be found at http://www.coastalmasterplan.louisiana.gov/.

REFERENCES

Alperin, Lynn M. (January 1983). History of the Gulf Intracoastal Waterway, National Waterway Study, Navigation History NWS-83-9.

Louisiana's Comprehensive Master Plan for a Sustainable Coast (2012)

Saving Louisiana's Coastal Wetlands, The Need for a Long-Term Plan of Action, Report of the Louisiana Wetland Protection Panel, Convened By Louisiana Geological Survey & U.S. Environmental Protection Agency, EPA #230-02-87-026. (April 1987).

The Impact of Federal Programs on Wetlands, Volume II, A Report to Congress by the Secretary of the Interior. (March 1994).

U.S. Geological Survey Fact Sheet 2010-3018; http://pubs.usgs.gov/fs/2010/3018/

© ASCE 2014

COMPLETING THE SUSTAINABILITY CYCLE: RECLAIMED WATER, PELLETIZATION, BIOGAS & SOLAR POWER

Stephen McGrew, P.E.[1] and Maurice Tobon, P.E. [2]

[1] Palm Beach County Water Utilities, 8100 Forest Hill Blvd., West Palm Beach, FL, 33413; PH (561) 493-6110; FAX (561) 493-6113; email: smcgrew@pbcwater.com
[2] Palm Beach County Water Utilities, 8100 Forest Hill Blvd., West Palm Beach, FL, 33413; PH (561) 493-6003; FAX (561) 493-6113; email: mtobon@pbcwater.com

Abstract

The Palm Beach County Water Utilities Department (utility) is one of the few utilities in the country to complete the "sustainability cycle" of recycling wastewater effluent, creating fertilizer from biosolids, and turning biogas into energy. The utility achieves these sustainability goals at its Southern Region Water Reclamation Facility (SRWRF) located in the central part of Palm Beach County. In addition, to further enhance the sustainability of the utility, the County recently completed one of the largest solar projects in the area. The utility is an industry leader in becoming a green utility and has the mission statement, "Best Water, Best Customer Service, and Best Environmental Stewardship." The foundation of becoming a green utility lies in reducing the environmental footprint through conservation, sustainability, energy efficiency, and greenhouse gas reduction. In addition to its sustainability efforts, the utility promotes conservation through an alternative water resources program, which includes the largest reclaimed water system in southeast Florida. The social benefits of the triple bottom line are further enhanced by created wetlands with a nature center and boardwalks for wildlife viewing.

Introduction

Photo 1 - SRWRF

The SRWRF facility (see Photo 1) has 22 million gallons per day (mgd) of reclaimed water filters that can be blended with an additional 4 mgd of nanofiltration membrane concentrate. Additionally, created wetlands use secondary treated wastewater effluent for rehydration. In order to promote the use of reclaimed water Palm Beach County has enacted a mandatory reclaimed water service area that is strategically located to recharge wellfields, thereby increasing sustainability of the surficial aquifer. Under an agreement with the Palm Beach County Solid Waste Authority biosolids produced at SRWRF are pelletized for

© ASCE 2014

fertilizer, which is a long-term sustainable disposal method. Anaerobic digester methane is converted into energy using reciprocal engine generator sets and is paralleled with the facility's 4,160 volt main switchgear. More recently a 162 kW solar energy project has been installed on the plant site to meet the green energy goals and reduce greenhouse gas emissions.

Reclaimed Water and Wetlands

The SRWRF supplies reclaimed water to customers through approximately 55 miles of piping to over 90 residential communities and golf courses. As part of the utilities Environmental Stewardship, two wetlands using secondary effluent water have been constructed.

The SRWRF facility was completed in 1991 to replace several smaller wastewater treatment plants (WWTP) and included reclaimed water treatment facilities. The initial phase of the reclaimed water facilities consisted of sand filters, a chorine contact chamber, and high service pumps with a total production capacity of 4 mgd. One key to the success of the program was the location of the facility, which is in a farm area and adjacent to an existing water treatment plant (WTP 3). The location allowed reclaimed water to be implemented as residential development replaced farm lands and provided a secondary benefit of recharging WTP 3 well field.

In 1996, the utility actively sought to increase the use of reclaimed water. Golf courses and large residential communities near the facility provided a source of reclaimed water users. In order to meet the increased demand, sand filters and transmission pipelines were constructed at the facility to increase the reclaimed water production capacity to 6 mgd from 4 mgd (Pica 2001).

In 1997 in order to further promote the use of reclaimed water, Palm Beach County adopted a reclaimed water ordinance and established a mandatory reclaimed water service area zone surrounding SRWRF. The mandatory reclaimed service area required new developments to utilize reclaimed water for irrigation. This innovative local government initiative became a model for other governments. Due to the success of this initiative, the mandatory reclaimed water zone was increased in 2005 from the original 4 sq mi to 10 sq mi.

In 1998, as the demand for reclaimed water increased the utility added 16 mgd of reclaimed water capacity by installing cloth filters, which resulted in a total reclaimed water capacity of 22 mgd.

© ASCE 2014

Photo 2 - Wakodahatchee Wetlands

Palm Beach County Water Utilities motto of Environmental Stewardship is evident by the construction of the Wakodahatchee Wetlands (Seminole for "created waters") in 1997 (see Photo 2). The wetlands were constructed adjacent to the existing WTP 3 at the former site of the WWTP 3 percolation ponds. The 39-acre wetlands utilize secondarily treated wastewater, which reduces the amount of effluent disposed through deep well injection. The wetlands were designed to treat the secondary effluent with natural biological processes to further reduce nutrient levels. Treated water from the wetlands percolates into the surficial aquifer which recharges the local groundwater. This recharging reduces impacts of well pumping on the regional surface water system. The Wakodahatchee Wetlands is considered a significant wildlife refuge, providing habitat for 119 bird species and includes a one-mile boardwalk and has a series of interpretive signage panels designed to inform and educate the public on the natural systems and wildlife.

Due the success of the Wakodahatchee Wetlands the County has also built a second wetland system known as Green Cay. The first phase of the Green Cay Wetlands was completed in 2004 and included 26 acres of open water for water fowl; 17.5 acres of uplands for nesting, resting, breeding and feeding activities; and emergent marsh for attracting wading birds and other wetland-dependent birds (see Figure 1). Walking trails along the two miles of boardwalk provide significant recreational opportunities for the community. The County's Parks and Recreation Department constructed a 10,000 sq ft world-class Interpretive Center at the Green Cay Wetlands. The center provides a living laboratory for school groups and

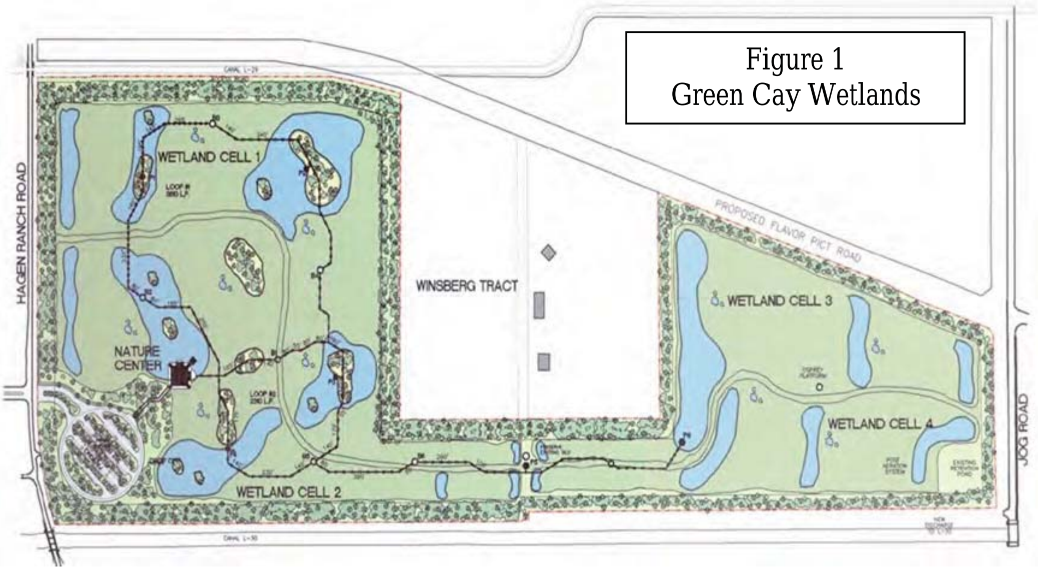


Figure 1
Green Cay Wetlands

© ASCE 2014

community organizations to study the hydrology, ecology, and restoration of southern Florida ecosystems. The created wetlands with nature center provide social benefits for the triple bottom line of environmental, economic and social conditions.

As demand for reclaimed water increased, the utility has utilized innovative methods to meet the demand of its customers. In 1999, the utility began routing a portion of the nanofiltration membrane treatment waste stream (membrane concentrate) produced at WTP 3 to the SRWRF. The membrane concentrate flow contains concentrated organics and minerals removed from the surficial aquifer raw water which is blended with the filtered secondary effluent upstream of the reclaimed water chlorine contact basins. A maximum blend ratio of at 5.24 parts reclaimed water to one part membrane concentrate is maintained per the Florida Department of Environmental Protection (FDEP) permit conditions.

The utility's reclaimed water program and wetlands program are multifaceted in the benefits they bring:

- Reduces dependence upon surficial aquifer and regional water supply system.
- Maintains a more consistent supply of raw water for treatment plants.
- Reduces the amount of fresh water drained from the land and discharged into the ocean.
- Minimizes stress on wellfields.
- Minimizes the "net" quantity of water withdrawn from the surficial aquifer.
- Provides landscaping water supply during drought conditions.
- Reduces reliance on deep injection well system.
- Educates the public on the importance of water conservation in South Florida.
- Increases carbon absorption by creation of wetlands.
- Provides habitat for migratory birds, waterfowl, and endangered species.
- Provides passive recreation opportunities for the public.
- Increases suburban green space.

Pelletization of Biosolids

The utility, working with the County's Solid Waste Authority (SWA) and five other public wastewater utilities, developed the concept of constructing a regional Biosolids Processing and Recycling Facility (BPF) to process wastewater residuals into

© ASCE 2014

a Class "AA" material used for fertilizer. The utility previously processed its wastewater biosolids to Class "B" standards, and these biosolids were land-applied. Land application of biosolids was not sustainable due to the increasingly stringent regulatory environment with fewer land application sites and higher costs.

On April 12, 2005, SWA approved a contract with the New England Fertilizer Company (NEFCO) to design/build/operate the BPF. Under an Interlocal Agreement SWA is responsible for the design, construction, operation, and maintenance of the regional BPF. In addition, NEFCO will market the biosolids pellets to various fertilizer manufacturers to be used for energy production (see Photo 3).

Photo 3 - SWA Pelletizer Facility

As part of the BPF screw and belt conveyors transport the material into two 460-cu-yd bins, and then into a pug mill, which mixes oversized and fine dried pellets with the incoming sludge. The mixture then enters one of the two rotary drum dryers (see Photo 4), which evaporates the moisture and condenses the remaining solid material into 2-cm pellets. Methane from the adjacent Class I landfill is used for the two 300-ton/day Baker-Rullman Mfg. Inc. dryers, rather than flaring it off, reducing dependence on natural gas and operating costs (Ludwig 2011). A separator cyclone then screens the dried solids (see Photo 5). Pellets meeting the size criteria are cooled and transported to storage silos, ready to be sold. The SWA pelletization facility became operational in 2009.

Photo 4 - SWA Pelletizer Rotary Dryer

Photo 5 - Biosolid Pellets

© ASCE 2014

Biogas to Energy

In 2010 the utility began the Digester Biogas Renewable Energy Project which generates up to 20 percent of the facility's power requirements from methane biogas that was previously flared and wasted. This project was partially funded by the United States Department of Energy's Energy Efficiency and Conservation Block Grant (EECBG) Program Assistance Agreement in the amount of $1.6 million, which covers a portion of the $3,529,000 project cost. This project demonstrates environmental stewardship per the utility's mission statement and is essential to the Department's green initiatives (McGrew 2013).

The SRWRF is a conventionally activated, sludge domestic wastewater treatment facility rated at 35 mgd, three-month average daily flow (TMADF) and is currently operating at approximately 60 percent of its rated capacity. Sludge is collected in the existing clarifiers and pumped to three gravity belt thickeners where the sludge is thickened to approximately 5 percent solids before being stabilized through anaerobic digestion. There are two digester groups, each with three 65-ft diameter digesters. Each group has two primary digesters with fixed covers and one secondary digester with a floating cover. These gas holder covers permit a cover travel of about 6 ft and thus provide up to 20,000 ft^3 of biogas storage per secondary digester. The facility digesters receive an average of 86,000 gal of solids per day with an average volatile solids concentration of 4.24 percent. This equates to an average of 30,000 lbs per day of volatile solids fed into the digesters. On average, the volatile solids destruction for the SRWRF digesters was 15,800 lbs per day, or 53 percent. During design it was assumed that 15 ft^3 of gas is produced per pound of volatile solids. Gas samples were analyzed to determine the British thermal units (BTU) available for combustion, and to measure hydrogen sulfide and siloxanes. The digester heating requirements were subtracted from the gas production to determine the available gas flow for the renewable generators. The criteria for sizing of the generators focused on minimizing flaring and maximizing energy production while considering seasonal flow variations. The selected generators are two 375-kW Internal Combustion Engines (see photo 6) which provide 96 percent gas utilization. To maximize the use of the 480V three-phase renewable generators, the power produced will be paralleled to the plant electrical grid. The electrical power will be increased to 4,160V through the use of transformers and then paralleled using the existing switchgear (see Photo 7). The electric power produced is used on-site, reducing the purchase of electric power which is produced using fossil fuels. This project is projected to generate an average of 455 kW of continuous electrical power, which will provide 20 percent of the required electrical power for SRWRF.

© ASCE 2014

Photo 6 – 375KW Biogas Engine Generator

Photo 7 - Biogas Generator Enclosures with Transformers

Critical decisions in the design of the biogas to energy project included determination of the gas volume, gas BTU quality and contaminants, operational protocol for digester pressures, sizing of gas pretreatment system, type of equipment for electrical generation, sizing and number of generators, how to connect the generated power to the plant power system, process control system for operations, and maintenance requirements. During pre-design, engineering evaluations included scenarios using both internal combustion engines, as well as microturbines. The internal combustion engine was chosen based upon higher efficiency and minimal gas preparation. The biogas to energy system utilizes two Waukesha Power Systems 375-kW internal combustion engine-generator sets, while maintaining the use of digester biogas as a fuel for the existing boiler systems. This combination results in utilization of over 96 percent of the current biogas generated at the facility with an energy cost savings of $283,000 per year. Each renewable generator is housed in a separate hurricane rated enclosure

To maximize the savings the biogas generators are programmed to run at 100% capacity during the hours that FPL charges peak rates. The peak rate hours vary from the summer air conditioning periods and winter heating seasons and are established by the FPL rate schedule. The programmable logic controller (PLC) operates the biogas to energy facility using the liquid level in the digester and the level of the floating digester cover to determine the gas volume. The PLC totalizes the gas being used by the biogas generators and the digester boilers. Prior to the peak rate hours the biogas storage volume is optimized using an algorithm to maximum power generation and increase savings on the facility's FPL power bill.

The gas pretreatment system (see Photo 8) consists of moisture and particulate removal with minimal gas compression. During the construction, General Electric Corp. (GE) purchased Waukesha. GE then reduced the allowable siloxane levels for biogas generators. During combustion these silicon containing gases produce abrasive microcrystalline silica which can damage engines. The silicon level in the

© ASCE 2014

lubricating oil has been measured to determine the required frequency for oil changes to protect the engine from this damage. The oil is being changed bi-monthly until a siloxane filter is added to the pretreatment system.

Photo 8 – Gas Pretreatment System

This waste gas-to-energy recapture is an innovative project that demonstrates sustainable use at a wastewater treatment facility. This has potentially widespread application in similar wastewater treatment facilities, as well as other industrial facilities located throughout Florida. In addition, this project provides the facility with additional electrical generation capacity in the event of an emergency or during a disaster.

The utility also values improvements that can increase positive public perception, and embraces environmental stewardship. There are six objectives that were achieved in the biogas to energy project:

Objective 1: Complete the "sustainability cycle" at the facility by utilizing up to 100 percent of the biogas created at the facility.

Objective 2: Reduce energy supplied by the power grid.

Objective 3: Provide source green power to meet the utility's 5 percent alternative energy goal.

Objective 4: Increase electrical system flexibility.

Objective 5: Reduce greenhouse gas emissions.

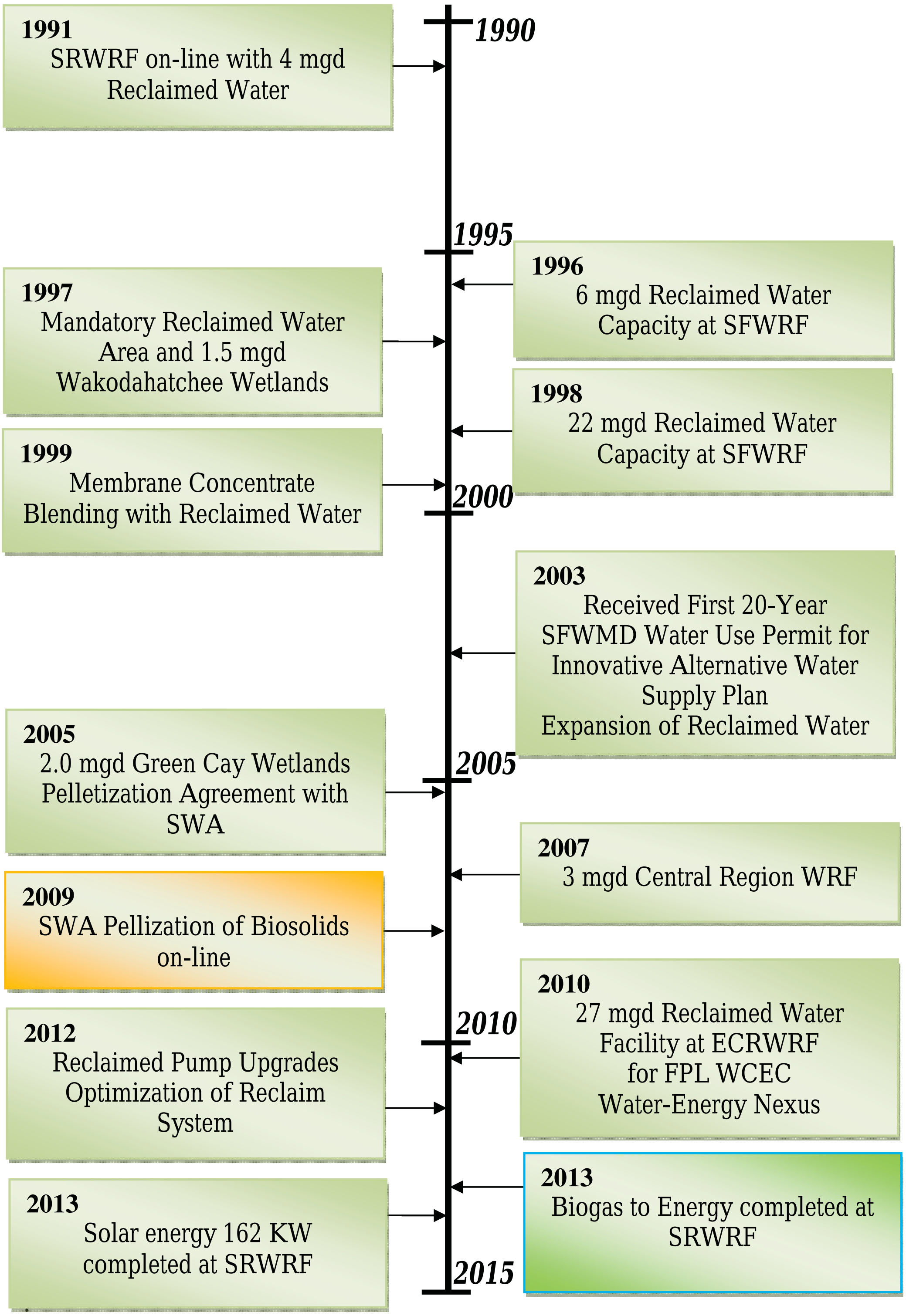
Objective 6: Become a model for other utilities to recover and utilize biogas for energy production.

Completing the "Sustainability Cycle" – Solar Power

The final piece of the "Sustainability Cycle" was the installation of 162 KW ground-mounted solar panels and was completed in the fall of 2013 (see Figure 2). The $925,000 project was partially funded through an ARRA green energy stimulus grant which covered $ 450,000 of the total cost. The solar panel system in conjunction with the digester biogas project now exceeded our utility goal of 5% alternative energy.

© ASCE 2014

Figure 2. Timeline of Palm Beach County's "Sustainability Cycle"



The solar panels are located within large buffer areas that contain both grassy lawn areas and tree canopy (see Photo 9). The Suniva MVX Series 250W solar panels were placed in the grassy area along the plant access roadway and are visible from the Florida Turnpike. The individual solar panels connect to combiner panels where the DC voltage is monitored through the plant SCADA system using Modbus communication protocol. The combiner panels connect to Solectria PVI 100 KW rectifiers where the DC voltage is converted to 480V, 3 Phase AC power (see Photo 10). The two rectifiers are then connected to the effluent pump building electrical gear (480V switchgear). Total yearly green energy production is estimated at 235,000 KWhr with an electrical savings of $20,000 per year.

Photo 9 - Solar Panels

Adding solar power to treatment facility is an environmentally sound business practice. It's a relatively easy to implement project in comparison with biogas to energy. Future expansion for the solar power may continue along the plant access roadway or mounted on the building roofs. We have ample space to expand the solar power from 162KW to 500 KW when there are additional funding opportunities to further increase green energy and reduce the carbon footprint.

Photo 10 - Solectria PVI 100 KW Rectifier

The utilities sustainability program extends beyond the SRWRF. The Central Region Water Reclamation Facility (CRWRF) was completed in 2007 with 3 mgd of reclaimed water filters treating secondary effluent from the East Central Regional Water Reclamation Facility (ECRWRF). In 2008, Florida Power and Light (FPL) entered into an Agreement for reclaimed water for the West County Energy Center (WCEC), a new 3,750 MW combined cycle natural gas turbine power facility. A 27 mgd reclaimed water facility was constructed at the ECRWRF with an 18 mile transmission pipeline to the WCEC to provide a sustainable source of evaporative cooling water (McGrew 2012). The total capacity of the utilities reclaimed water and wetland program including the SRWRF, CRWRF and ECRWRF is now 59.5 mgd.

The completion of the "Sustainability Cycle" of recycling wastewater effluent, creating fertilizer from biosolids, and turning biogas into energy along with the new 162 KW solar power generation project is a model of Environmental Stewardship.

© ASCE 2014

References

1. Pica, L.L., and McGrew, S. (2001). "Palm Beach County Water Utilities Alternative Water Resources Plan." Florida Section AWWA Conference.

2. Ludwig, V. (2011). "Self-Sustaining Biosolids Drying: How Solid Waste and Wastewater Authorities are Joining Forces to Limit Energy Costs." Public Works Magazine, http://www.pwmag.com/government-projects/self-sustaining-biosolids-drying.aspx?dfpzone=general.

3. McGrew, S., and Rivera, D. (2013). "The Sustainability "Hat Trick": Reclaimed water, Pelletization of Biosolids, and Biogas to Energy." Florida Water Resources Journal, 65 (3).

4. McGrew, S.M., and Tobon, M., (2012). "Design and Construction Challenges for a 36 Inch Diameter 18 Mile Reclaimed Water Pipeline." ASCE Pipelines 2012

© ASCE 2014

Waterfund/IBM
The True Cost of Water

Prepared for the American Society of Civil Engineers (ASCE)
International Conference on Sustainable Infrastructure (ICSI) 2014

Dr. Peter Williams, CTO, IBM "Big Green Innovations", and IBM Distinguished Engineer [a]
Scott Rickards, Founder & CEO, Waterfund [b]

[a] IBM Corporation, 425 Market Street, San Francisco, CA 94105 PH (925) 648-7975 email peter.r.williams@us.ibm.com
[b] Waterfund LLC, 701 Brazos Street, Austin, Texas, 78701 PH (514) 705-6655; email scott.rickards@worldswaterfund.com

Abstract
Investment in the provision or replacement of water infrastructure has historically failed to meet the need by a wide margin. One reason for this has been the historical tendency for water to be underpriced, or not priced at all: this has made it difficult to demonstrate a reasonable return from any investment and difficult to assess risk. To address this issue, Waterfund LLC, assisted by IBM, has created the Rickards water cost index that will track the cost to supply drinking quality water globally, eventually covering the supply underpinning 25% of the globe's GDP. The index, which uses leading edge data-analysis techniques to derive inputs from unstructured data in water agency public documents, represent a novel application of what is sometimes called "big data" to water management.
The oil industry will tell you that $100/barrel oil is the value below which capital allocation can earn a return. Given its critical importance in our lives, why does the water industry not have a similar answer to the question? Is the 'global water crisis' a resource crisis or perhaps a capital crisis?
Precisely because of its critical importance, the water industry has been given a pass on cost transparency by everyone from politicians, to Wall Street, to economists due to the unimaginable consequences of not having an abundant supply of fresh water. As a result, the subject of water production costs remains largely unexplored and water has taken a back seat to virtually every other resource in the battle for private investment dollars. The large scale and non-uniformity of water financial data is also a major challenge to creating a precise water finance benchmark; no two water enterprises publish comparable financial statements. Water volumes, interest expense, energy costs, and capital expenditures must first be extracted from unstructured data sets often thousands of pages in length. Then, hidden costs and subsidies must be interpolated and modeled alongside the available information. Complex data challenges such as these are the main barriers to a successful and precise global water cost index.
This paper will describe the techniques used to construct the index and how it will be used to enable higher levels of investment in water supplies and water infrastructure.

© ASCE 2014

"The things which have the greatest value in use have frequently little or no value in exchange; on the contrary, those which have the greatest value in exchange have frequently little or no value in use. Nothing is more useful than water: but it will purchase scarce anything; scarce anything can be had in exchange for it. A diamond, on the contrary, has scarce any use-value; but a very great quantity of other goods may frequently be had in exchange for it"

- Adam Smith, "An Enquiry into the Nature and Causes of the Wealth of Nations", 1776

Background – A Failure of Supply to Meet Need

Water has been perceived to be underpriced for many hundreds of years, as Adam Smith's famous "Diamond-Water Paradox" shows. Smith was not the first to note this: Copernicus and Locke had mused on the subject even before Smith. For as long as water did not attract a valuation that matched its use, there was little direct financial return to be had from investing in water systems, meaning that the impetus to invest had to come from some other motive, such as civic duty or general economic development.

As a result of the lack of a compelling financial case, the capital investment backlog in water infrastructures globally is now estimated in the $billions and sometimes $trillions. The well-known "Report Card" grade of D+ given the USA from the American Society of Civil Engineers (ASCE) underscores the long-term investment failure of both the private and public sectors. Of course, this American failure pales with the "infrastructure gap" globally where an estimated 780 million people today have never had the benefit of a piped water infrastructure that delivered drinkable (or, often, any other) water in the first place.

Unfortunately, civic duty and general economic development funds no longer provide sufficient funding for the water industry. As long as water does not attract a price reflecting its true value, there will be no direct financial return and little incentive for investment in the water sector. The underfunding of the water industry has created significant drought risk in many parts of the world. Given the risks to industry, food production, health, and ultimately life, the importance of attracting the necessary capital to build water infrastructures that can provide reliable, consistent, and long-term supplies of freshwater is critical.

Under pressure from climate change, growing populations and economic activity, the finite nature of water resources is now in many parts of the world becoming apparent. In addition, ancient infrastructures in some areas imperil economic activity, and increasingly affluent and informed populations are demanding better services. The water sector is therefore becoming ever more aware that it has to balance needs to address the investment backlog and close the infrastructure gap. This will require

© ASCE 2014

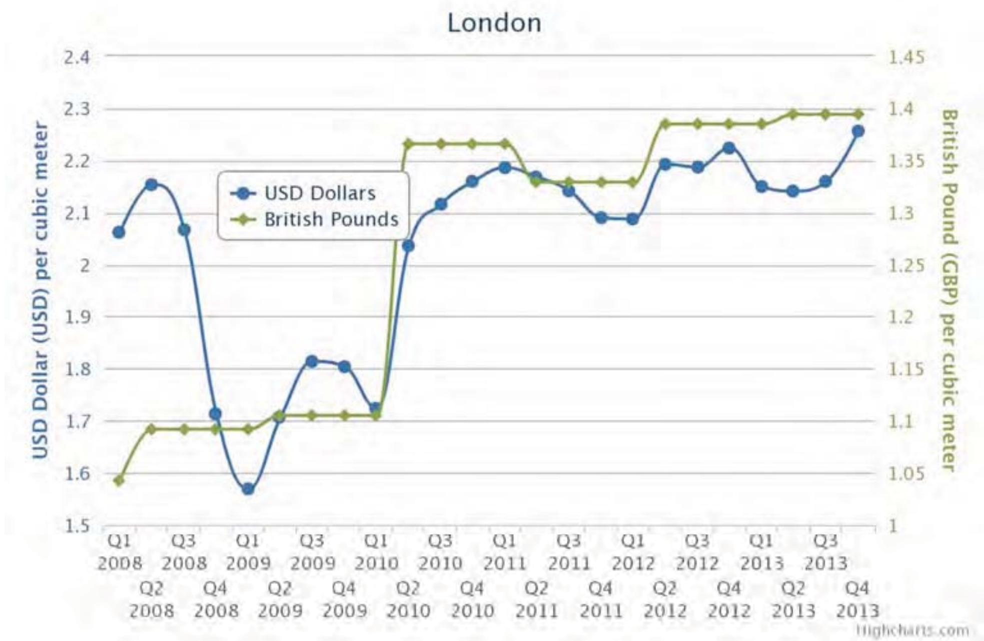
very large capital inflows that the sector has not historically been able to attract. Also, while rising costs will over time make a financial return from investing in water easier to demonstrate, gauging risk remains problematic. The Water Cost Index (WCI) is designed to address these needs.

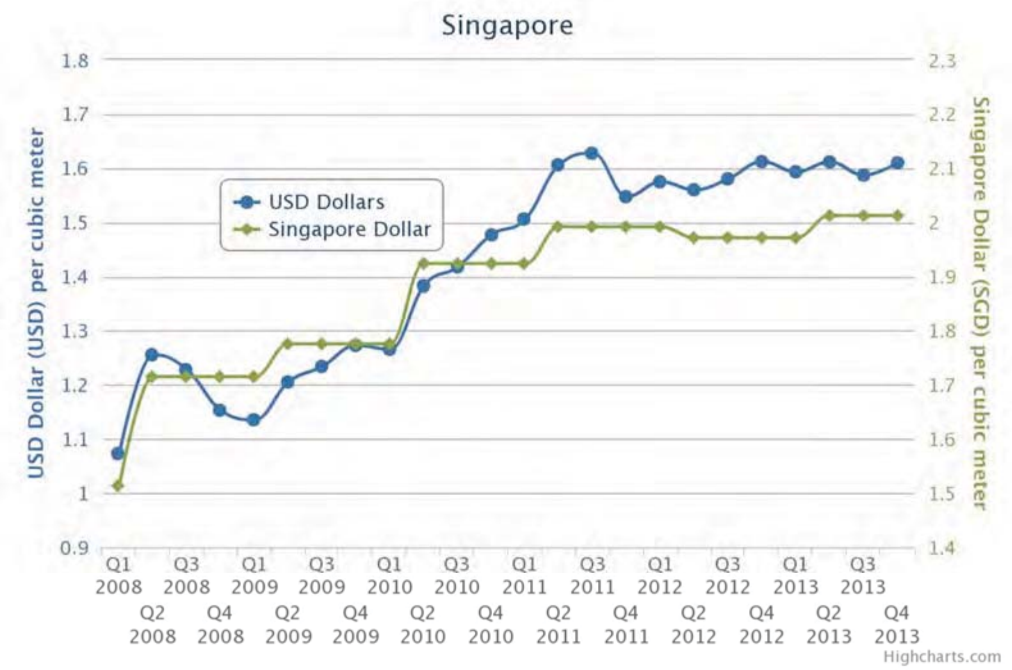
Finding equilibrium between supply and demand of water infrastructure capital relies on answering a fundamental economic question: at what cost is it economical for the world's largest cities to bring additional water supply online? The oil industry typically uses $80-100/barrel oil as the value which capital allocation can earn a return. Given its critical importance in our lives, why does the water industry not have a similar simple answer to the question? To what extent is the "global water crisis" in fact a capital crisis, as opposed to the resource crisis that it is usually assumed to be?

Precisely because of its critical importance, the water industry has given a pass on cost transparency by everyone from politicians, to Wall Street, to economists due to the unimaginable consequences of not having an abundant supply of fresh water. As a result, the subject of water production costs remains largely unexplored and water has taken a back seat to virtually every other resource in the battle for private investment dollars. Perhaps the water industry's "social protection" has done more harm than good. Indeed, the consequences are already clear: the global water business is riddled with underinvestment and lack of financial reporting standards.

To be clear, the subject of water scarcity has not been ignored. Indeed, there are a number of benchmarks and even exchanges which value the scarcity of physical supply. Chile has an electronic water exchange as does Australia and several other important water-short regions. Others have attempted indices which measure the scarcity value of physical water supply; some have attempted to quantify the financial impact of water pollution in creating trading schemes designed to cap that pollution.

What's missing in these marketplaces and valuation metrics is an accounting of the massive capital spending required between the raw resource and the production of "finished water" at your tap. Uganda is endowed with widespread and plentiful natural water resources, yet 93 percent of the country does not have access to piped water in their home. What's worse, the 93 percent that remain unconnected to the water network pay far higher prices that Americans and Europeans. Facts such as these lead one to believe that the "global water crisis" is in fact, to a significant degree, also a market failure. Again, finding equilibrium between supply and demand will depend on properly valuing the production cost of water.


London
USD Dollars
British Pounds
USD Dollar (USD) per cubic meter
British Pound (GBP) per cubic meter
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
Q1 2008
Q2 2008
Q3 2008
Q4 2008
Q1 2009
Q2 2009
Q3 2009
Q4 2009
Q1 2010
Q2 2010
Q3 2010
Q4 2010
Q1 2011
Q2 2011
Q3 2011
Q4 2011
Q1 2012
Q2 2012
Q3 2012
Q4 2012
Q1 2013
Q2 2013
Q3 2013
Q4 2013
Highcharts.com


Singapore
USD Dollars
Singapore Dollar
USD Dollar (USD) per cubic meter
Singapore Dollar (SGD) per cubic meter
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
Q1 2008
Q2 2008
Q3 2008
Q4 2008
Q1 2009
Q2 2009
Q3 2009
Q4 2009
Q1 2010
Q2 2010
Q3 2010
Q4 2010
Q1 2011
Q2 2011
Q3 2011
Q4 2011
Q1 2012
Q2 2012
Q3 2012
Q4 2012
Q1 2013
Q2 2013
Q3 2013
Q4 2013
Highcharts.com

© ASCE 2014

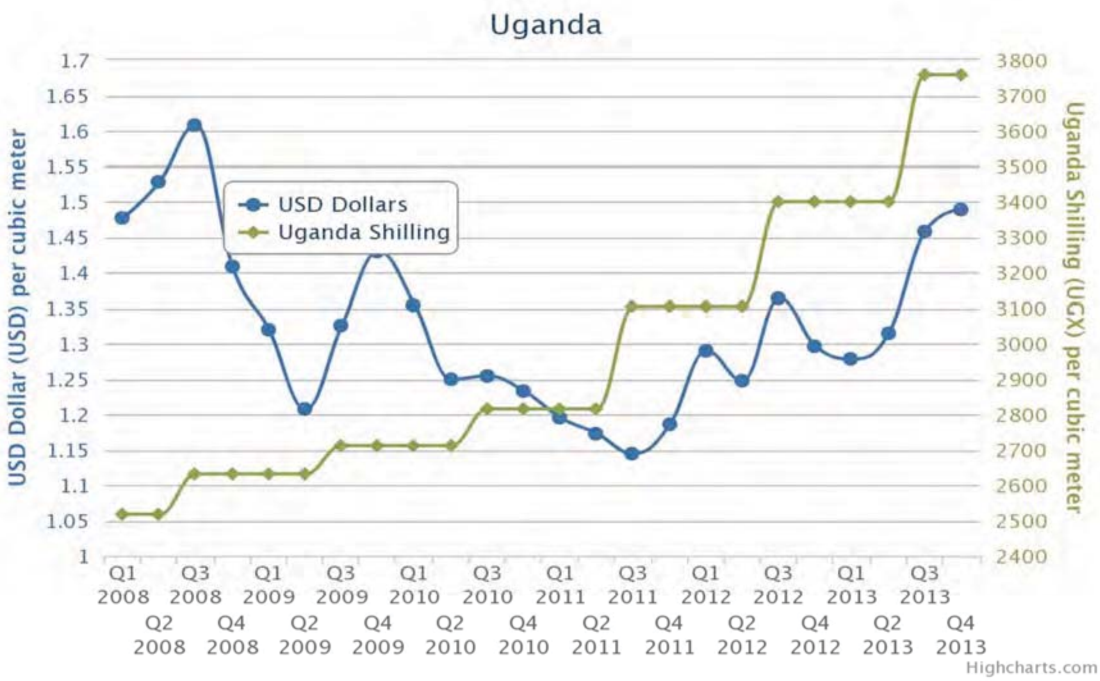


Figure 1. Current Water Cost Indices (WCI) in USD and Local Currency

The technology and engineering capabilities to dramatically improve and solve water infrastructure issues exist today. Modern technology reduces water loss, improves energy efficiency and decreases wear and tear on infrastructures. Water banking and reservoir expansion can dramatically increase storage capacity to help dry regions get through long periods of drought. Water systems can be built connecting areas with an abundance of water to areas that experience drought. Desalination plants can turn brackish and salt water into healthy potable water much more efficiently with solar and other new technologies. And modern metering systems can provide feedback to consumers to advise them of consumption levels with (often in conjunction with tiered pricing levels) proven results in prompting the reduction of that consumption.

Large scale projects like these require overcoming legal (i.e., water rights) and political hurdles. They also demand significant capital investment. The private sector can provide vast amounts of additional capital, if it is properly incentivized. Imagine if 20% of the amount of capital that is invested in the energy sector, invested in the water sector. The water infrastructure would be significantly improved.

The good thing about a crisis is that it can be a catalyst for change. Water awareness grew considerably in California and Texas as they recently experienced severe droughts. Most critically, retail-level awareness prompted the political will to upgrade water infrastructures and begin to undertake major water projects. Increasingly affluent and informed populations in developing countries are even more demanding of their governments for better services as they realize outdated water infrastructures imperil economic activity. The water sector is therefore becoming ever more aware that it has to address the water project backlog. Specifically, the water sector needs to find ways to attract additional capital investment. Reducing risk and enhancing return on investment (ROI) are the primary solutions for increasing investment activity. Waterfund's Water Cost Index (WCI) is designed to help mitigate investment risk while improving ROI.

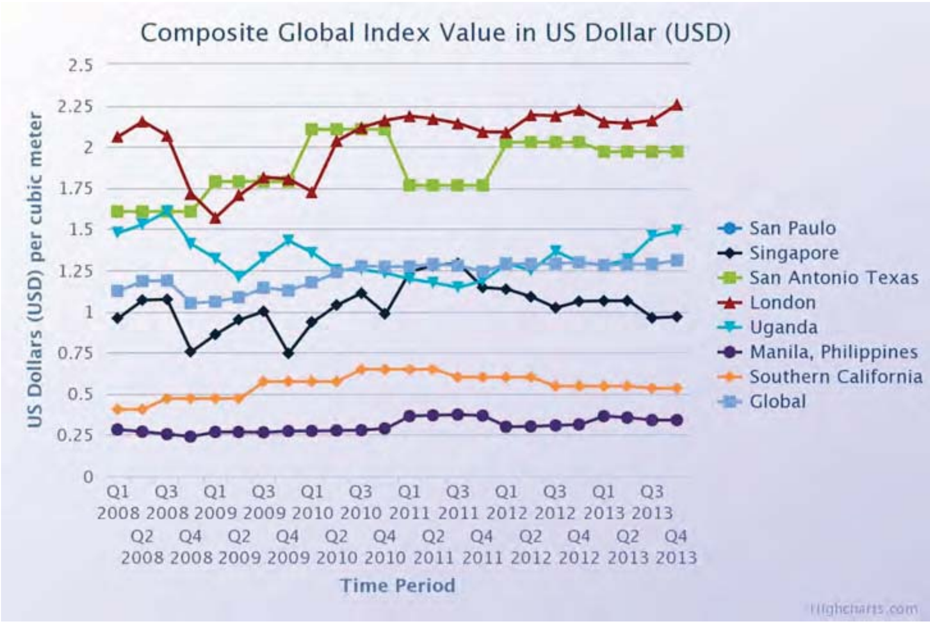


Figure 2. Water Cost Indices (WCI) – Seven Cities

Water Cost Indices Reduce Financial Risk

The Water Cost Index being developed by IBM and Waterfund seeks to shed light on what it costs the world's major cities to produce and deliver a unit of "finished water". The Water Cost Index will enable the creation of water cost benchmarks that can be used to trigger insurance payments, adjust water rates, set water tariffs, and perform financial analysis. For example, suppose the business case for a water recycling and transmission project is dependent on the eventual value of the water produced. The project's owners could reduce the risk that this represents to investors by taking out a hedging product that pays out when the Water Cost Index fails to rise over a certain level, or when the index displays volatility above a certain threshold. This risk reduction will make investment in the project more appealing.

The same principle might apply to investments designed to reduce non-revenue water, whose return on investment (ROI) is dependent on the value of water saved. The Index could be used to underwrite the value of saved water, thereby de-risking the investment and enabling it to proceed. At the same time, the WCI would also be

© ASCE 2014

a tremendous metric to measure the improved efficiency created by reducing non-revenue water.

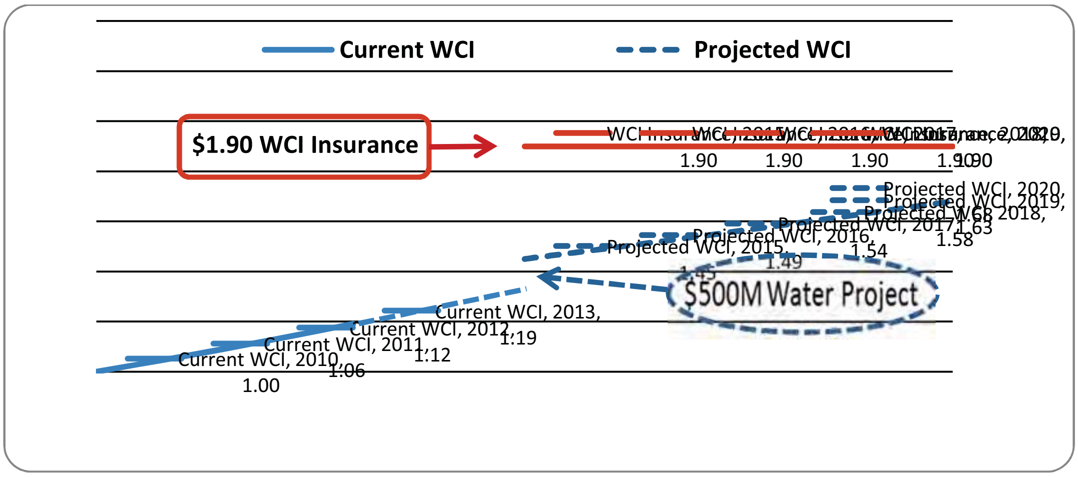


Figure 3. WCI Hedging Example

It may be asked why water agencies could not use "inflation indices" such as the CPI[1] to hedge risk – why a separate index is needed. In practice, the CPI and other inflation benchmarks have an extremely low correlation with water costs: Waterfund's aggregate WCI increased over 30% over the past five years while the CPI grew less than 10%.

[1] CPI is the All Urban Consumers CPI-U as calculated by the US Department of Labor Bureau of Labor Statistics: US Dept. of Labor Statistic CPI-U

© ASCE 2014

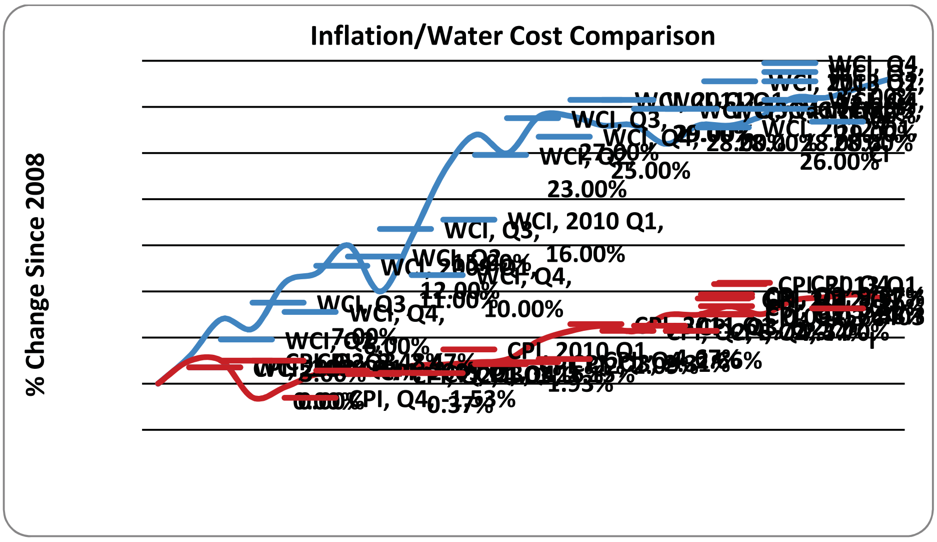


Figure 4. A Better Benchmark For the Water Industry – CPI vs WCI

In addition to attracting private investment into the water industry, public investment (i.e., tax-exempt municipal finance) will also improve as credit agencies raise bond ratings to reflect the risk reduction.

WCIs will also help water managers operate their business and improve efficiency by providing users with customizable analysis tools, including: 1) WCI applications using IBM's calculation agent to make pro-forma projections (through extrapolation algorithms) about future water costs, and 2) Project finance applications that perform what-if scenarios about proposed capital spending programs and their impact on overall water production costs.

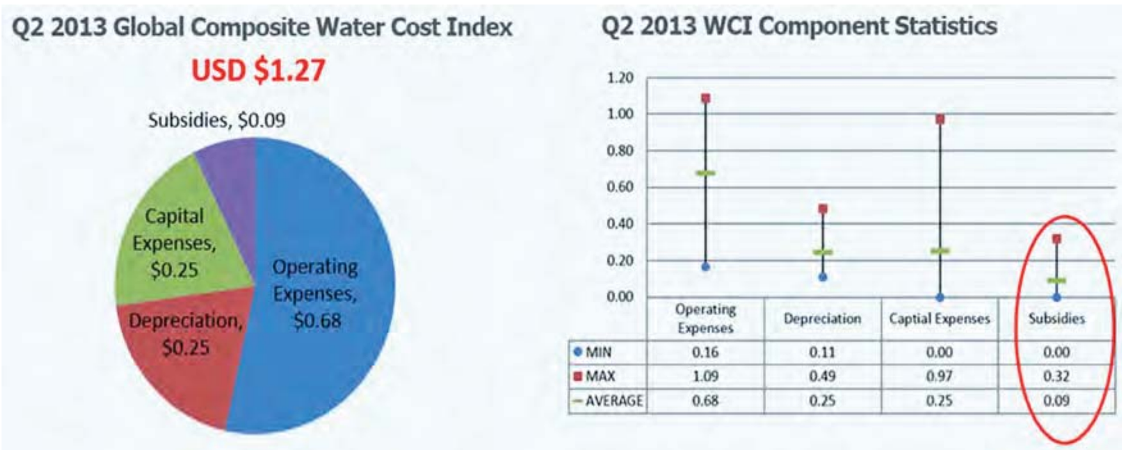


Figure 5. Data Analysis

Looking ahead, the time when water utilities will employ third-generation financial data and products in the same manner as the energy industry is not in the far distant

© ASCE 2014

future. With pension funds in need of reliable, long-term asset allocation, Wall Street in need of ever-growing industry segments for risk, and water companies in dire need of capital, the time has come for such innovations to be realized. Once again, the WCI will serve as an ideal input for determining a price. Indeed, the Index could in time become the foundation for a global market in water risk and trading.

Once complete, the index can be used to ring-fence and manage risk exposure to major water infrastructure projects. To take one specific example, the Jordan Red Sea Project seeks to take in and desalinate water at the Red Sea and deliver it via pipeline to severely water-stressed Amman, Jordan and the Dead Sea. The geopolitical upside of a successful outcome to this project is obvious, but total project costs run upwards of $25 billion dollars. Billions have already been pledged by major governments and the World Bank has recently given its seal of approval. However, private investment will certainly be required. If the index could be used to create hedging instruments to underwrite the investment exposures of private financiers in situations such as the dire one faced in Jordan, so enabling the investment to take place, it would be a valuable tool in changing how business gets done in the water industry and in extending and revamping the world's water infrastructures.

Index Calculation

IBM constructs and operates the official Calculation Agent using an algorithm that can be simply expressed by the following formula:

(energy costs + operating expenses + capital expense + interest expense) / volume of water supplied

As straight-forward as the WCI formula appears, the actual computation is far more complex as the graphic below shows.

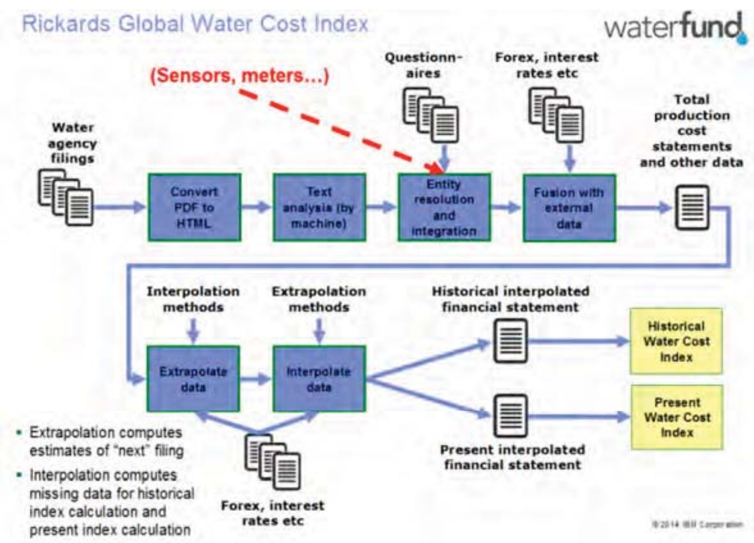


Figure 6. Technical Architecture of IBM Calculation Agent for Water Cost Index

© ASCE 2014

The construction and calculation of the index is a genuinely ground-breaking application of analytic techniques for unstructured data. Water agency data, if published at all, is highly variable in quality and format. The context of any given data value (footnotes, additional comments, or even just placement on the flow of the text) may be critical to how it should be interpreted. Additionally, treatment of numerous ancillary items such as accrued pension liabilities, energy and capital subsidies need to be carefully considered. These and other issues make achieving the consistency required to build an index a highly challenging exercise.

Fortunately, Waterfund and IBM Research's Accelerated Discover Lab have the expertise and technical capabilities to capture, dissect, refine, and ultimately produce reliable Water Cost Indices. Values for all cost variables are standardized, and have single, well-defined semantics. This allows for a direct comparison of relevant costs for each producer. The data is then manually reviewed and adjusted to produce the finished result. Consistency in the calculation methodology is critical to produce like-for-like outputs. The specific technical challenges that must be overcome to scale IBM's index calculation agent are as follows:

Analyzing Unstructured Public Data: A key source of financial information is the audited financial reports that individual agencies publish periodically for the benefit of their shareholders, financiers, or general public. These documents are usually text documents (in pdf or html format) that need to be analyzed to identify the financial information reported within various sections of large (100+ page) documents. These documents are typically for human consumption and processing them programmatically raises multiple challenges such as the ability to accurately analyze various concepts of interest such as financial tables or footnotes mentioning cost variables, and the need to process various types of text documents.

Isolating cost variables and identifying both direct and indirect cost subsidies: The cost variables that contribute to the true cost of production are reported in various parts of the financial statements depending on whether they are "explicitly reported costs" or "hidden costs". For instance, operating expenses is typically reported as expenditure in the Income Statement, while government grants may be reported as revenue in the Income Statement; further breakdown of individual costs such as operating expenses may be elaborated in textual notes associated with the financial statements. The ability to extract the individual cost variables from various parts of the reports and combine them from multiple filings over time to create a complete temporal view for each producer is important.

Accounting for filing discrepancies: Agencies occasionally change, over time, their reporting formats or the way in which they break down specific financial details. The ability to identify these discrepancies while combining data from multiple filings and resolving them, either programmatically or through intelligent alerting of a data steward is a key requirement.

Addressing missing information: Agencies report their financial information periodically, usually quarterly or annually, and even this information is typically

© ASCE 2014

available only after a lag of a few months. Therefore, the last available financial report could be over a year old in many cases. Additionally, data reported in financial statements may be incomplete (e.g., the cost of raw water may not be reported, and must be estimated). In order to have a complete and up-to-date Water Cost Index for all regions, it is imperative to address this missing data problem by estimating the missing values using advanced statistical techniques.

Each location will have its initial WCI backdated five years and reported on a quarterly basis. The performance of a water producer can now be benchmarked against other producers in the same geographic region or globally. A producer can be benchmarked on individual cost variables as well, which provides additional insight into their cost structure and the relative risk it presents. The individual WCI locations will be able to be broken down for further analysis and combined to create regional sub-indices. Waterfund plans for the Water Cost Index to eventually cover 25% of the world's GDP or roughly 100 of the largest cities.

We now focus, in some detail, on four main technology components together with their challenges. The four technology components that we discuss are: PDF to HTML conversion, information extraction (with particular emphasis on extraction from tables), entity integration (including temporal fusion and reconciling of inconsistent information), and statistical analysis.

PDF Conversion

For many application use cases, the publicly available financial data is only available in PDF format, and must be converted to text before subsequent analytics is possible. For example, the data for the municipal bond and water index applications in Section 2 are only available as PDFs from MSRB EMMA and water producer websites, respectively. The main challenges for converting PDF to text are table identification, extracting correct table structure, and handling character recognition errors.

Capturing table structure along with the text data enables automated attachment of semantics to table cell values during information extraction, mimicking what a human reader of the table does. For example, a financial filing contains multiple tables with financial data similar to Figure 6a. Intuitively, the table title and headers provides semantic context to table contents. Surprisingly, an OCR engine is required to capture table structure from a PDF, even for programmatically created ones, since position information for text blocks on the page are required. Most commercial OCR engines have a table detection and table structure inference algorithm. However, these algorithms are not completely correct. The OCR generated HTML output for the table in Figure 6a is shown in Figure 6c. The title for the table and the first row header are incorrectly placed in the same row as the rest of the column headers.

We make two observations to provide context for this example. First, the OCR generated output for this table has a moderate level of errors. Many other tables have

© ASCE 2014

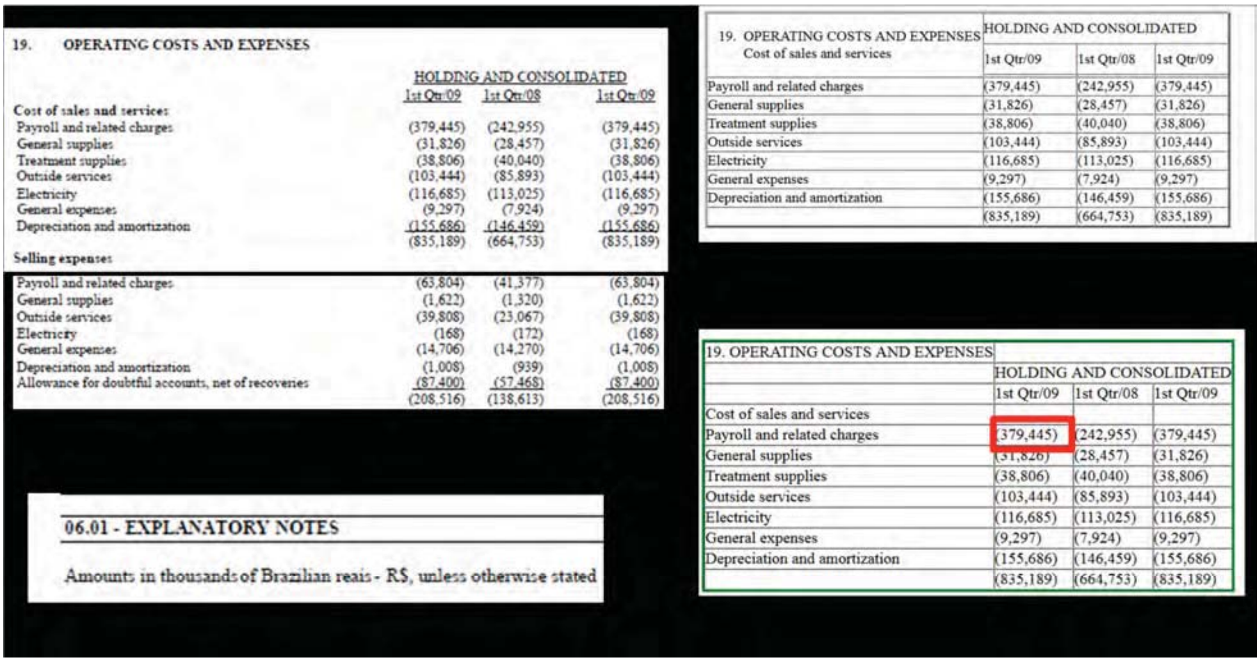
worse errors in the OCR output, including complete failure to identify a table region. Second, even this this seemingly minor error of not properly separating the row header from the title can lead to major mistakes in semantics attributed to table values, as the example in the next section illustrates. We address this challenge by leveraging the raw output from the OCR engine with positional information for each text block on the page to correct the HTML generated by the built-in table recognition algorithm in the OCR engine. The result of our correction algorithm for Figure 6c is shown in Figure 6d. In our experience, character recognition errors were not an issue for the commercial OCR engine. However, one area for further exploration is leveraging the text available in a programmatic PDF to detect and correct recognition errors introduced by the OCR engine.

Information Extraction

For information extraction, we leverage SystemT and its declarative language AQL for expressing information extraction rules with SQL-like syntax. In addition to extracting information from unstructured free-owing text, we use a collection of AQL rules to associate semantics with text data included in HTML tables. This collection of AQL rules performs the following operations listed below, which are generic across all data in tables. The declarative nature of AQL supports using the same set of AQL rules across all three application use cases described in Section 2, with minimal domain-specificity tuning (e.g., different lists of relevant table titles for filtering tables by title).

Additionally, there are non-obvious semantics which must be associated with the table cell as well. The row header `Cost of sales and services' for the row of blank cells should be associated with the block of rows beneath it, until the next row header for a blank row `Selling Expenses'. Thus, the two rows in Figure 6a with row header `Payroll and related charges' have two different meanings. The first refers to payroll for producing water, while the second refers to payroll related to billing user accounts, advertising, etc. Extracting this distinction is important, since the former is an expense that should be included for calculating the water cost index (direct cost of producing water) while the latter should be excluded (indirect cost of billing water). In the example, we observe the table is missing information regarding currency and denomination of the values. However, from the same document we extract from free text (shown in Figure 6b) that all table values are in thousands of Brazilian Reais, unless otherwise stated. Thus, the full semantics of this example table cell, as automatically extracted by SystemT from the document, is: for the main water utility and all subsidiaries in the first quarter 2009, the payroll cost associated with sales and services (i.e., producing clean drinking water only) are 379,445,000 Brazilian reais. This semantics is identical to what a human expert reading the entire 89 page document would assign, since the table in Figure 6a (page 57) and the unstructured text in Figure 6b (page 24) are separated by 23 pages.

© ASCE 2014



19. OPERATING COSTS AND EXPENSES

	HOLDING AND CONSOLIDATED		
	1st Qtr/09	1st Qtr/08	1st Qtr/09
Cost of sales and services			
Payroll and related charges	(379,445)	(242,955)	(379,445)
General supplies	(31,826)	(28,457)	(31,826)
Treatment supplies	(38,806)	(40,040)	(38,806)
Outside services	(103,444)	(85,893)	(103,444)
Electricity	(116,685)	(113,025)	(116,685)
General expenses	(9,297)	(7,924)	(9,297)
Depreciation and amortization	(155,686)	(146,459)	(155,686)
	(835,189)	(664,753)	(835,189)
Selling expenses			
Payroll and related charges	(63,804)	(41,377)	(63,804)
General supplies	(1,622)	(1,320)	(1,622)
Outside services	(39,808)	(23,067)	(39,808)
Electricity	(168)	(172)	(168)
General expenses	(14,706)	(14,270)	(14,706)
Depreciation and amortization	(1,008)	(939)	(1,008)
Allowance for doubtful accounts, net of recoveries	(87,400)	(57,468)	(87,400)
	(208,516)	(138,613)	(208,516)

06.01 - EXPLANATORY NOTES

Amounts in thousands of Brazilian reais - R$, unless otherwise stated

19. OPERATING COSTS AND EXPENSES Cost of sales and services	HOLDING AND CONSOLIDATED		
	1st Qtr/09	1st Qtr/08	1st Qtr/09
Payroll and related charges	(379,445)	(242,955)	(379,445)
General supplies	(31,826)	(28,457)	(31,826)
Treatment supplies	(38,806)	(40,040)	(38,806)
Outside services	(103,444)	(85,893)	(103,444)
Electricity	(116,685)	(113,025)	(116,685)
General expenses	(9,297)	(7,924)	(9,297)
Depreciation and amortization	(155,686)	(146,459)	(155,686)
	(835,189)	(664,753)	(835,189)

19. OPERATING COSTS AND EXPENSES			
	HOLDING AND CONSOLIDATED		
	1st Qtr/09	1st Qtr/08	1st Qtr/09
Cost of sales and services			
Payroll and related charges	(379,445)	(242,955)	(379,445)
General supplies	(31,826)	(28,457)	(31,826)
Treatment supplies	(38,806)	(40,040)	(38,806)
Outside services	(103,444)	(85,893)	(103,444)
Electricity	(116,685)	(113,025)	(116,685)
General expenses	(9,297)	(7,924)	(9,297)
Depreciation and amortization	(155,686)	(146,459)	(155,686)
	(835,189)	(664,753)	(835,189)

Figure 7. Sample Data

Entity Integration

Entity integration, as the architecture in Figure 5 suggests, applies after the text analytics phase and has the goal of putting together all the extracted facts (e.g., from text, from tables) into the structured entities that are of interest for the application. In our particular implementation, we leverage HIL, a SQL-like language that can be used to express the rules for mapping to the target entity model, together with the necessary operations for aggregation and fusion of the data values, including resolving inconsistencies.

We use the Water Cost Index application as an illustration for some of the entity integration challenges, since this application is quite different from the more traditional settings for data integration. First of all, the mapping to the target entity model is very different from traditional schema mapping scenarios. While the target model (or schema) for the Water Cost Index is well-defined and reflects the important attributes in a Normalized Production Cost statement, there is no source schema in the traditional sense. The only notion of schema that is encoded in the extracted data comes in the form of the various terms that refer to rows, columns, row headings or table titles, and which accompany the actual cell values. Furthermore, different agencies, and even different filings within the same agency, may often use different terms to refer to the same conceptual attribute or structure. Thus, a big part of the challenge is to capture the wide heterogeneity in the input terms and structure, in a way that is customizable and extensible. The particular solution we adopted for the Water Cost Index splits the mapping logic into two components. First, the skeleton of the mapping logic is expressed as HIL rules, where each rule, for a particular line item in the target statement, is generic (i.e., independent of the particular terms used in a source). However, each rule is parameterized by a set of dictionaries that are used

© ASCE 2014

to identify the relevant tables, rows, headings, as well as columns that map to a given line item, for a given agency. These dictionaries can be customized by a human expert, to account for the various idiosyncrasies in how different agencies report. Adding a new water agency to the system requires adding the relevant terms in the dictionaries, without having to change the structure of the rules. Additional challenges in developing the entity integration logic for the Water Cost Index are related to handling errors and inconsistencies in the reported data. First of all, oftentimes agencies restate their numbers one quarter later or, sometimes, one year later. As a result, the HIL rules that diffuse across different filings for a given agency and a given time period, must look at values that span multiple filings for the same line item and apply conflict resolution. In this application, for each line item, if we have different numbers coming from different filings, we give priority to the latest reported numbers. Last but not least, our solution also allows to incorporate manual overriding by a human expert.

This step takes as input the automatically generated Normalized Production Cost statements and fuses them with a user-given statement. In this type of fusion, we always give priority to the user-given values. We leave out any discussion of other entity integration challenges (e.g., entity resolution which is relatively well understood), and focus next on statistical analysis.

Statistical Analysis

Many applications can be built by performing statistical analysis over the results of the curated set of entities and relationships. The Water Cost Index is calculated for each producer by performing statistical analysis over the cost variables in the Normalized Production Cost Statement, which were populated by each entity integration. This statistical analysis is performed using algorithms implemented in a scripting language with R-like syntax, called DML, which executes on the scalable machine-learning platform

Conclusion

The WCI is a ground-breaking innovation in several respects. First, it addresses a problem with water valuations that is many hundreds of years old, and will enable desperately needed capital investment into the water sector. Second, the WCI and other data derived from the calculation will provide financial analysis tools that help the water industry improve efficiency. Finally, the calculation process represents the current "state of the art" in automated analysis of highly unstructured data – a major contribution to the current movement around "Big Data". Waterfund and IBM are pleased to have presented their innovation as an example of the kind of approaches needed to combat the effects of global population and urbanization on earth's water resources.

© ASCE 2014

References

Smith, Adam (1776), "An Enquiry into the Nature and Causes of the Wealth of Nations"

U.S. Department of Labor Bureau of Labor Statistic. "Consumer Price Index Data from 1913 to 2104" http://www.usinflationcalculator.com/inflation/consumer-price-index-and-annual-percent-changes-from-1913-to-2008/

© ASCE 2014

Applying Sustainability Principles To Benefit the Overall Project Delivery Cycle of Infrastructure Systems

Peter D Binney, P.E., ENV SP, M.ASCE [1]

[1] Vice President, Sustainable Infrastructure, Merrick & Co. 5970 Greenwood Plaza Blvd., Greenwood Village, CO 80111; Phone (303)353-3709; email peter.binney@merrick.com

ABSTRACT

It has been widely reported that critical and necessary upgrades, operational changes and expansion of infrastructure systems have fallen behind in meeting society's needs. Desirable or required levels of service and resilience are increasingly compromised because of that lack of investment in the future. Economic losses resulting from traffic congestion, drought impacts to agriculture, cities and businesses as well as regional impacts from power outages would seem to present a compelling case for government agencies to move expeditiously to deliver reliable and resilient infrastructure systems. Historically, this has generally been the case. However, recent trends including higher levels of environmental protection, wider civic engagement, more expansive regulatory requirements and constrained financial resources, have contributed to decreased performance, or extended delivery schedules or shelving of critical infrastructure systems.

This paper investigates the potential gains in project delivery that could be realized by applying the triple bottom line principles – namely the social, environmental and economic elements – of sustainability to the planning, design, construction and operation of those critical infrastructure systems. Work flow process improvements can assist with the technical definition of infrastructure systems. Sustainability principles can also guide policy makers, interested stakeholders and community leaders as they promote consensus approaches that are more balanced than the extremes of absolute opposition or with forcing disruptive or damaging infrastructure approaches. The sustainability rubric to project planning has been applied for decades in manufacturing and corporate business settings and more recently in building systems as guided by LEED and Green Globes assessments. Now those principles can be incorporated into public and private infrastructure planning through systems such as Envision™ as presented by the Institute for Sustainable Infrastructure (ISI) and American Society of Civil Engineers (ASCE).

A retrospective case study for a municipal water system is presented to describe how a sustainability framework for the planning and design could be applied throughout the project delivery cycle for infrastructure projects.

INTRODUCTION

Major deficits or delays in the approval, financing and construction of critical transportation, water, energy and other infrastructure systems are occurring in many parts of the country. Communities are experiencing impacts that should be addressed to meet deferred and current

© ASCE 2014

infrastructure needs but also prospectively as the Nation's population increases to over 400 million by year 2050. During that period, it is expected that more than 70% of that populace will be concentrated in urban areas. Population densification and expansion of infrastructure needs will have to be addressed in more effective ways.

Business activity and community vitality are adversely affected and ecosystems can be compromised if those infrastructure needs are not provided for in an efficient manner. It is estimated that billions of dollars are being lost because of traffic congestion. As a result, agricultural, power and economic activity are being compromised through lack of service. For example, in 2010 drivers in U.S. urban areas are estimated to have wasted 1.9 billion gallons of fuel while idling in traffic jams for over 4.8 billion hours. The total costs of this waste and delay over the past decade would be almost one trillion dollars. In Texas alone, annual economic losses from not meeting water supply needs under the drought of record conditions could result in a reduction in income of approximately $11.9 billion annually. That loss could be as much as $115.7 billion annually by year 2060 with over one million jobs lost. Coastal/ riparian environments and communities affected by extreme weather events are making daily headlines. These observations and associated public angst should be responded to with a comprehensive, transparent and outcome-based approach to infrastructure programs that could be built around a work flow process that is guided by sustainability principles.

That goal of providing adequate and necessary infrastructure solutions is not intractable The design and construction of infrastructure systems could be facilitated through a systematic consideration of social and environmental values that balance objectives and levels of participation or investment with the desired functional performance of those infrastructure system and available funding. This is not to advocate a return to the pre-environmental movement days when large infrastructure projects could have severe environmental and social consequences as the expense of functionality alone.

Sustainability principles respect and incorporate the broad range of cause and effect to multiple stakeholders. They can identify and promote balance points where project configurations include acceptable approaches with appropriate mitigation elements and with acceptable financial consequences.

The social science of balancing competing needs of stakeholder groups requires a high level of transparency, interaction and information sharing so informed consent is reached – it may be that the outcome is rejection, modification or approval with acceptable mitigations or other conditions that parties can agree to. The workflow process following sustainability principles can provide an objective and reasoned framework for seeking input, recognizing varying considerations and identifying alternative paths for resolution while establishing whether and how an infrastructure project can be configured and delivered.

LIFE CYCLE ASSESSMENTS AND APPLICATION OF SUSTAINABILITY PRINCIPLES

Application of sustainability goals has a desired outcome for informing stakeholder groups and facilitating the decision making process as well as delivering increased functionality of new or

© ASCE 2014

refurbished infrastructure systems. The practicing engineer can use the breadth of sustainability principles and sustainability assessments across the life cycle of infrastructure projects to facilitate that project delivery cycle and manage the project delivery schedule. For example, the development of major new water systems in the western United States has often taken multiple decades from concept to commissioning. There are many instances nowadays when regulatory approval has delayed vital water system improvements as the public and regulators work to balance a wide range of societal, ecosystem and other values that are influenced by the adaptation for modification of historic water settings. This comes at a time of increased need for reliable water supplies to serve burgeoning urban economies against a backdrop of uncertain water supply conditions in the future.

These have always been important but are now increasingly so with the deficit in infrastructure systems and the increasing reliance on public private partnerships for which time to completion is a financial imperative. They can also and enhance the financial effectiveness of investments. Often, the solutions are not constrained by technology or the ability to identify solutions but rather the complexity of normalizing the public and political dialogue associated with a major change in existing water conditions and practices.

While life cycle assessments (LCAs) are commonly used for integrating economic factors between capital and operating costs, those assessments can be expanded to consider other project delivery frameworks. LCA's are also a tool that are increasingly used to analyze the life cycle of activities or products as guided by ISO 14040 and 14044. Commercially available software packages like SimaPro and GaBi include a number of databases and methodologies for various resource management issues such as carbon footprinting. Specific applications that deliver high energy efficiency buildings such as Autodesk Revit are focused on building applications than what is anticipated for large public works infrastructure programs.

There are unique aspects to public works infrastructure programs that life cycle sustainability assessments (LCSA's) should be able to address than are typical for well-defined building applications. These include the multiple and inter-related elements that public infrastructure owners and design teams must address. Those inter-related elements can include at least the following:

1. Project Formulation and Complexity of the Decision Making Process;
2. Project Purpose and Need;
3. Design Standards and Uncertainty;
4. Regulations and Policy (including application, issuance and compliance);
5. Civic Engagement and Activism;
6. Community Outreach, Education and Participation ;
7. Infrastructure Projects in Highly Developed Settings and Urban Centric Society;
8. Project Financing;
9. Project Delivery Systems;
10. Supply Chains;
11. Procurement and Contracting;
12. Safety;

© ASCE 2014

13. Quality Assurance and Quality Control.

Rather than considering each of these elements in isolation through snap shot assessments (see Figure 1) or through a subset of assessments for a limited set of project development phases, it is offered that public works infrastructure projects should be assessed over a full life cycle approach. Figure 1 indicates a series of individual sustainability assessment snapshots that could be conducted at the various stages of planning through operation and decommissioning a public works infrastructure project. While each of the individual assessments can be instructive, the sustainability assessment over the life cycle should be considered as a method for integrating decisions throughout the project development cycle. This is observed as a means for guiding the owner through the concept development phase and the resulting regulatory approval process and its public involvement and political approval stage. This can limit the unintended consequences of crystallizing design decisions in isolation and more effectively managing the cost and schedule commitments that are made.

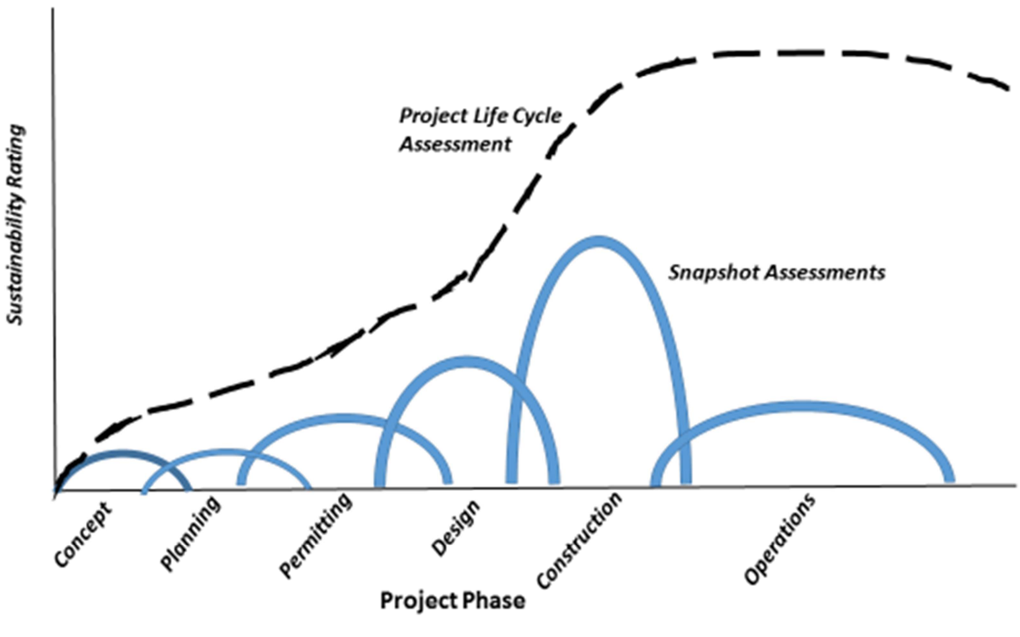


Figure 1 - Snap shot versus sequential considerations versus dynamic planning framework

The value of sustainability assessments can be greatly enhanced when the owner or engineer considers policies, programs and projects as an integrated framework. Those cause and effects of decisions are seen to propagate and influence performance throughout the life cycle of the infrastructure system. Integrated Resource Plans (IRPs) and other forms of strategic planning can be guided at a higher level by the LCSA approach.

© ASCE 2014

That integrated assessment is desirable because of a number of factors:

1. The design of infrastructure projects will dictate how society uses a particular infrastructure systems and therefore will directly affect the environmental and social benefits and impacts;
2. Designs can and should be adapted to identify appropriate solutions that manage impacts on ecosystems while enhancing benefits to society;
3. Those relative adaptations of individual project elements should be made within the fiscal parameters and scheduled delivery dates that are described by the owner and supported by the community;
4. The design phase for infrastructure projects is where the greatest influence (suggested as being greater than 80%) and management of ecosystem and social benefits or impacts can be influenced;
5. The design (and planning) phase should be considered as the primary point in the life cycle that can drive innovation and opportunities to manage ecosystem and societal impacts and benefits;
6. The tradeoff between the multiple planning and design criteria can be made within an integrated framework (the LCSA) that compares, establishes levels of achievement and identifies the consequences of those decisions.

The following case study illustrates of a sustainability rating system that provides a comprehensive view of how a public works project could be influenced by a broad spectrum consideration of triple bottom line criteria.

CASE STUDY – AURORA DRINKING WATER SYSTEM; PRAIRIE WATERS PROJECT

The case study describes an operational project that was conceived, authorized, designed, constructed and commissioned between mid-2005 and late-2010. This is a retrospective view of a major public works project that was completed prior to the formal adoption of Envision by ISI. No formal verification of the project has been requested so the following illustrations are prepared by the author who was the Director of Aurora Water, was the architect of the project concept as well as a formative member of the Envision sustainability rating system team. The case study is illustrative and intended for general guidance and should be used for that specific purpose. Opinions of sustainability performance are entirely those of the author and represent a compound view of the life cycle from concept through the initial years of operation.

Aurora Colorado is a major municipality in the Denver metropolitan area with a service population of over 300,000 people and a planning population of 500,000 people by year 2035. The municipal drinking water system had been developed by the City over the prior 50 years. Water sources were primarily secured from transferred agricultural water rights and inter-basin transfers of surface waters with limited use of non-tributary and non-renewable deep aquifer waters. The water system had been operated successfully over decades of average to above average hydrologic conditions. The City was able to maintain high levels of service and unrestrained tap commitments without costly expansions of the raw water system. Demand

© ASCE 2014

management programs were nominal. Costs of service were not adjusted regularly, in part because excess system capacity and the lack of major capital investments could be accommodated within a rate structure set in the early 1990's.

The drought of 2002 and following years rapidly depleted the city's reservoir carryover storage accounts and historically low runoff conditions quickly compromised water deliveries to customers by spring 2003. Before spring runoff, the City had less than three months of water in storage while normal operating conditions would have provided 2-3 years of average demand conditions. Acute water availability conditions required immediate responses at that time. The immediate needs of the City water supply system were met by a very aggressive water restriction program (water conservation plus) that reduced primarily outdoor water use by 35%. Indoor water usage was reduced by 5% - 8% by changing household water practices. Lowered municipal demands were supplemented on the supply side by deliveries from a rotational fallowing program of agricultural water rights, short term leasing of industrial water sources and upgrades to the water treatment capabilities of the treatment plants so they could adequately treat marginal quality sources. The limitations on treatment capability were observed after low water quality from runoff of wildfire burn areas in the watersheds led to severely limited production capacity of the two water treatment plants. A fast-track design-build water treatment plant upgrade helped address that specific operational constraint. These responses provided bridge solutions but longer term reliability and growing service needs resulting from population growth, hydrologic uncertainty and financing capacity were still to be addressed.

The better understanding of the reliability and resilience of the City's water supply portfolio under drought conditions indicated the need for a major and rapid expansion of the City's capacity to meet water demands and desired levels of service. Similar projects across the Western United States that conventionally develop new source water can often take at least several decades to bring new supplies to the tap. The water utility was therefore challenged with formulating an approach that could deliver new source water at the earliest date, within acceptable cost of service envelopes and would be supportable by customers while meeting all local, state and federal regulations and requirements.

Using Sustainability Principles as a Project Implementation Tool over The Project Life Cycle

The following illustration describes how some of the key success factors in delivering this complex and major public works project in an expedited schedule would be influenced by a Sustainability Assessment. The representation is shown for the full project cycle from concept to commissioning and for the startup phases for operations. When initiating the project concept, the following performance indicators were used as the key framework planning tools:

1. Address drought shortages by increasing water availability in shortest effective schedule;
2. All drinking water quality across entire distribution system to be identical to current snowmelt-derived sources;
3. All local, state and federal regulations to be fully complied with;

© ASCE 2014

4. New water sources to be integrated within current water supply system and expandable as future growth requires additional source water;
5. Project approach should be acceptable to and supportable by customers and City Council;
6. Increased cost of service should be reasonable and apportioned to current customers for enhanced quality of service and to future customers through higher tap fees.
7. Bond financing should be supported by a transparent and managed risk disclosure to credit rating agencies.

Early in an integrated resource planning step, City staff realized that there were there were few options to develop classic water sources as used in the past – snowmelt and mountain storage – given the anticipated several decade schedule to secure unappropriated surface waters that could be reasonably interconnected to the existing raw water system. The chosen path forward was essentially to develop a planned indirect potable reuse project based on the City's continued and perpetual ownership of the use of the majority of its first use water based on the provenance of those water rights (see insert box).

> “Using water to extinction”
>
> *An appropriator who lawfully introduces foreign water into a stream system from an unconnected stream system may make a succession of uses of such waiter to the extent that its volume can be distinguished from the volume of the streams into which it is introduced.*
>
> *Colorado Revised Statutes 148-2-6 (1963).*

By using these property rights, the City achieved a number of key sustainability goals:

1. No new water sources had to be developed with consequent impacts on the environment or watersheds of origin;
2. The City did not impose its growth-related needs onto other areas of the State;
3. By multiple uses of an existing developed water source, the City effectively doubled the utility of previously developed water sources.
4. The planned infrastructure to introduce those source waters could be expanded to additional agricultural areas that could participate in rotational fallowing and drought protection programs and therefore enhance the viability of continued farming operations without a freehold sale of their water and lifestyles.

As identified in the retrospective sustainability review, there were also a number of key areas where the project would rate poorly or unattractively. Those areas included:

1. Cost of service; to construct the project, the City increased its base water cost from \$2/1000 gallons to over \$4.50/ 1000 gallons and a water tap increased in cost from \$6800 to over \$20,000 per single family equivalent tap;
2. The project required pumping water over 34 miles with a dynamic lift of 1200 feet through three pump stations so the energy intensity for water deliveries was significant;
3. The new source water was significantly degraded by runoff from a metropolitan area of over 2 million people and discharges from an advanced secondary wastewater treatment plant that constituted almost all river flows during winter months. Energy and chemical

© ASCE 2014

intensive treatment processes were required to produce a finished water quality non-discernible from snowmelt runoff and this was achieved with capital investment and an ongoing operational improvement program.

Results of Sustainability Assessment

To demonstrate the application of the Envision rating system, the author completed a self-assessment of the project for the full life cycle of the project. This assessment did reflect the planning decision process for the City's full raw water system as well as the specific response that was adopted so it is an amalgam of snapshots that could have been taken at the various stages of the implementation plan.

The results of that assessment are shown in Figure 2. A number of the Envision criteria were not applicable to this particular project and several key characteristics were not reflected in the assessment. What would have been of significant value to City staff and their consultants would have been the use of a comparative assessment tool like Envision to confirm the balancing and degree of investment made in specific areas to secure approvals and progress. For example, the construction season for certain segments of the pipeline had to be constrained to accommodate bald eagle nesting areas at critical times of the year. A key decision had to be made regarding the additional costs and schedule impacts for tunneling under jurisdictional rivers and canals to comply with regulations that protect Waters of the United States. Decisions regarding the nine successive treatment, monitoring and intervention steps that were chosen to assure public acceptance of the new source water would guide the education and awareness programs.

The results of the self-assessment illustrate the strengths and limitations of the project delivery cycle and facility configurations. The balance between key metrics and the degree of achievement for the sustainability criteria represents the "right" formula for this particular setting and project need. Many of the actual decisions and balancing that were undertaken by the project team are reflected in the rating system and its availability at the time would have served as an effective primer to the team.

CONCLUSIONS

Defining infrastructure system needs or characteristics is rarely a technical challenge to today's engineers with the experience, professional judgment and tools that are now available. This is an affidavit to the systematic training, education, standards and codes and professional conduct of the professional engineer.

© ASCE 2014

Credit Category	Applicable Points	Points	Innovation Points	Total Points Pursued	Percentage of Available Points
QUALITY OF LIFE	101	70	8	78	69%
LEADERSHIP	106	89	5	94	84%
RESOURCE ALLOCATION	159	77	8	85	48%
NATURAL WORLD	158	102	5	107	65%
CLIMATE AND RISK	101	60	3	63	59%
Total Workbook Points	625	398	29	427	64%

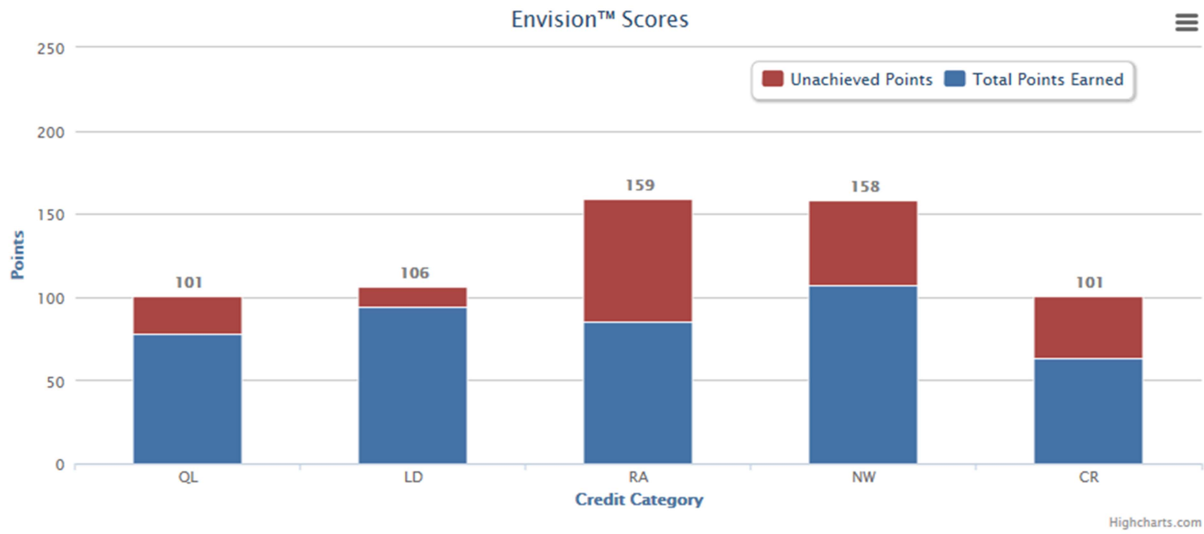


Figure 2 – Life Cycle Sustainability Assessment – Prairie Waters Project, Aurora, Colorado

The "infrastructure gap" that has developed across the United States (and indeed around the world) would appear to be more related to how engineers are contributing to solutions and whether technical input is addressing the "real" problems which are often political, societal, activist, regulatory or inertia related to a non-constructive tension between proponents and opponents. To remain relevant to the delivery of responsible infrastructure systems, engineers can be guided by a work flow process that is constructed around a comprehensive framework of sustainability criteria that considers how technical solutions will affect environmental, social and economic factors. These outcome based effects can be influenced by the degree of mitigation and investment that can be determined through interactive dialogue with value-based groups and regulators. The objective of this approach is to determine whether consensus can be reached on project attributes and operations – a negotiated settlement that requires skills in defining the key areas of concern and what would be an acceptable accommodation that can be identified within project constraints such as schedule and cost.

The project proponent may often find that ulterior motives ("no growth") or value-based participation is obscuring the project development process. The responsibility of the project team is not to describe technical solutions but also to facilitate the approval or determination process. The use of sustainability rating systems like Envision ™ are useful not only to

© ASCE 2014

categorize the level of achievement but more dynamically as a work flow planning framework to reach consensus and concurrence with a project plan.

REFERENCES

Texas Water Development Board (2012): *Texas Water Plan*, http://www.twdb.texas.gov/waterplanning/swp/2012/

Texas Transportation Institute (2011): *Urban Mobility Report*, http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobility-report-2012.pdf

© ASCE 2014

Raising the Grades – Sustainable Solutions to Infrastructure Challenges

A. Herrmann[1]

Abstract

Engineers play a unique role in the built world—planning, analyzing, designing, building, and rebuilding things that touch the planet—and therefore have an optimal and natural role in changing the built environment to meet new needs.

The 2013 Report Card for America's Infrastructure found that our nation's roads, bridges, and other infrastructure systems are in serious need of repair and modernization. The sixteen infrastructure sectors evaluated in the comprehensive report earned a cumulative grade of D+, with the lowest grades of D - going to levees and inland waterways. As the nation faces a daunting backlog of rehabilitation and replacement projects, how do we ensure that we build in a more sustainable way to maximize limited resources?

Sustainability strategies were examined in three key infrastructure sectors: transportation, water, and energy. Solutions range from bringing existing infrastructure to a state of good repair, using technology and non-structural methods to get more capacity out of road lanes, and managing demand through conservation strategies.

[1] Principal, Hardesty and Hanover, aherrmann@hardesty-hanover.com

© ASCE 2014

Infrastructure has a lifespan, and it will come as no surprise that our nation's roads, bridges, and water pipes are aging from coast to coast. Far too many of our nation's infrastructure systems lack the funding needed for proper maintenance. The American Society of Civil Engineers (ASCE)'s *2013 Report Card for America's Infrastructure* gave the nation's infrastructure a D+, inching up slightly from the overall grade of D in 2009. The grades in 2013 ranged from a high of B- for solid waste to a low of D- for inland waterways and levees. Solid waste, drinking water, wastewater, roads, and bridges all saw incremental improvements, and rail jumped from a C- to a C+. No categories saw a decline in grade this year.

Consider these facts:

- One in nine of our nation's bridges are rated as structurally deficient, and the average age is 42 years old.
- Nearly 45 percent of Americans lack access to any transit system in their community.
- America's aging electric grid includes over 400,000 miles of transmission lines, and has seen increasing power outages from 2007 to 2011.
- There are an estimated 240,000 water main breaks across the United States each year.

Engineers play a unique role in the built world—planning, analyzing, designing, building, and rebuilding things that touch the planet. With our nation's infrastructure assets aging and entering what AWWA calls the "dawn of the replacement era", we have a tremendous opportunity to rethink how we build the infrastructure of tomorrow. The goal is to rethink how to build, maintain, and repair America's infrastructure with an eye toward the future.

One thing to note is that the urban environment is of increasing importance, as US city centers become more condensed and new megaregions start appearing. Today, US cities with populations of at least 150,000 are home to 80 percent of Americans and generate almost 85 percent of the nation's GDP. By 2050, the US population is expected to grow to about 439 million, compared to 310 million in 2010. That is a 42 percent increase in 40 years. Worldwide there will be 9 billion people in 2050 compared to 6.9 billion today.

Infrastructure systems have to be ready to handle the burden of the megaregions in new, sustainable, and resilient ways. How can we as engineers and thinkers change how we think about and build the urban environment?

Even with the enormous backlog of projects across infrastructure sectors, the 2013 *Report Card* demonstrates that when investments are made and projects move forward, conditions improve and the grades rise. Continuing the momentum to "raise the grades" will require that we seek and adopt a wide range of solutions under three main categories:

© ASCE 2014

1. **Bold leadership and a compelling vision.** America's infrastructure needs bold leadership and a compelling vision at the national level. During the 20th century, the federal government led the way in building our nation's greatest infrastructure systems from the New Deal programs to the Interstate Highway System and the Clean Water Act. Since that time, federal leadership has decreased, and the condition of the nation's infrastructure has suffered. Currently, most infrastructure investment decisions are made without the benefit of a national vision. That strong national vision must originate with strong leadership at all levels of government and the private sector.

2. **Promote sustainability and resilience.** America's infrastructure must meet the ongoing needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management, and at the same time protect and improve environmental quality. Sustainability, resiliency, and ongoing maintenance must be an integral part of improving the nation's infrastructure. Today's transportation systems, water treatment systems, and flood control systems must be able to withstand both current and future challenges. As infrastructure is built or rehabilitated, life-cycle cost analysis should be performed for all infrastructure systems to account for initial construction, operation, maintenance, environmental, safety, and other costs reasonably anticipated during the life of the project, such as recovery after disruption by natural or manmade hazards. Both structural and non-structural methods must be applied to meet challenges. Infrastructure systems must be designed to protect the natural environment and withstand both natural and man-made hazards, using sustainable practices, to ensure that future generations can use and enjoy what we build today, as we have benefited from past generations.

3. **Develop and fund plans to maintain and enhance America's infrastructure.** While infrastructure investment must be increased at all levels, it must also be prioritized and executed according to well-conceived plans that both complement the national vision and focus on systemwide outputs. The goals should center on freight and passenger mobility, intermodality, water use, and environmental stewardship, while encouraging resiliency and sustainability. The plans must reflect a better defined set of federal, state, local, and private sector roles and responsibilities and instill better discipline for setting priorities and focusing funding to solve the most pressing problems. The plans should also complement our broad national goals of economic growth and leadership, public safety, resource conservation, energy independence, and environmental stewardship. Infrastructure plans should be synchronized with regional land use planning and related regulation and incentives to mitigate the growing demand for increased infrastructure capacity.

This paper is focused on finding sustainable ways to maintain and modernize

© ASCE 2014

infrastructure systems. Sustainability is critical to infrastructure that works in a world with more people and more significant infrastructure needs. Examining three key areas of infrastructure—water, energy, and transportation—we find some creative ways that engineers are using sustainable strategies to tackle infrastructure challenges across the country.

Water

At the dawn of the 21st century, much of our drinking water and wastewater infrastructure is nearing the end of its useful life. Assuming every drinking water pipe would need to be replaced, the cost over the coming decades could reach more than $1 trillion, according to the American Water Works Association (AWWA). Capital investment needs for the nation's wastewater and stormwater systems are estimated to total $298 billion over the next 20 years. Pipes represent the largest capital need, comprising three quarters of total needs. Fixing and expanding the pipes will address sanitary sewer overflows, combined sewer overflows, and other pipe-related issues.

In addition, many regions in the United States are juggling competing needs for water between municipal and domestic users, agricultural and industrial users, and the environment. Population growth, urbanization, and climate change will continue to stress water resources and accelerate the need for new solutions to conserve, supply, treat, store, and distribute water. Worldwide, nearly 800 million people lack access to clean water and 2.5 billion lack access to sanitation.

What should engineers be doing?

- Find new methods for making upgrades and repairs to aging infrastructure to fix leaks that waste billions of gallons of water every day.
- When designing and building new water infrastructure, or repairing or replacing existing infrastructure, ensure that the owner considers investments that are cost effective over their life cycle, are resource efficient, and are consistent with community sustainability goals.
- Reclaim and/or restore surface water bodies in wetlands to naturally filter out and remove contaminants. If designed properly, restored creeks and wetlands can offer greater flood protection and enhance city cooling.
- Develop new sources of water, such as desalination plants, tertiary water treatment for recycled water use, or rainwater collection treatment and redistribution systems.

Case Study: Prairie Waters Project

During 2003, the city of Aurora, Colorado, was months from needing to ration water to maintain a dwindling supply decimated by a severe drought. With a municipal water system serving 300,000 people on the brink of collapse, city leaders developed

© ASCE 2014

the Prairie Waters Project to ensure that it was capturing all the water the city currently owns in wells near the South Platte River's bank for use by Aurora residents.

The water collected is piped 34 miles to a new purification facility near the Aurora Reservoir that combines natural purification with advanced engineering solutions. The facility is designed to work in conjunction with the project's natural purification area, where water percolates with the natural sand and gravel found along the river. Because this process purifies the water naturally, there is no waste that must be discharged back into the river, and it greatly reduces the demand on more energy-intensive filtration.

Colorado's volatile water market makes purchasing additional water resources time-consuming and expensive. Not only is the project cost-effective through developing already owned water resources, but other design and operation features work together to maximize the use of city funds and encourage a more sustainable solution.

Case Study: Riverbank Filtration Tunnel and Pump Station project

The Riverbank Filtration Tunnel and Pump Station project at the B.E. Payne Treatment Plant in Louisville, Kentucky, was developed to exceed new regulations required by the Safe Drinking Water Act that will take effect in 2012. Riverbank filtration is a "green supply" purification process that uses the natural filtering processes of the riverbank to remove many of the particles and contaminants from the raw river water, which produces 70 million gallons of clean water each day. The Louisville Water Company is the first water utility in the world to combine a gravity tunnel with wells as a source for drinking water.

This $55 million-dollar project was designed to save money because the naturally filtered water requires less treatment and the stable water temperature results in fewer water main breaks. Water from the Ohio River is filtered through the natural sand and gravel of the riverbank and then is pumped into the plant for additional treatment. This filtration process improves public safety by reducing risks associated with hazardous chemical spills and removing herbicides, pathogens, and pesticides in the water.

Planners also worked closely with the local community to find a solution that would preserve the aesthetics of the neighborhood. Since River Road is part of a National Scenic Byway with historic homes along the river, the decision to use a deep underground tunnel to collect the water as opposed to above-ground wells was important.

Case Study: Philadelphia Water Department

The Philadelphia Water Department found that energy was one of their largest costs for operating their wastewater treatment plants. So, they designed a facility to convert waste into energy at their Northeast Water Pollution Control Plant, saving over

© ASCE 2014

$600,000 in energy costs after just their first winter season. The Biogas Cogeneration Project was designed to generate 5.6 MW of power for on-site use. As a natural byproduct of sewage treatment, biogas can be refined and utilized as fuel for generators and equipment. Carbon emissions are expected to be reduced by nearly 22,000 tons per year, which equates to the removal of over 4,800 cars off the road or the planting of over 5,000 acres of pine forest. On an annual basis, the project will produce about 85% of all the electrical energy used for plant operations.

Energy

America relies on an aging electrical grid and pipeline distribution systems, some of which originated in the 1880s. Investment in power transmission has increased since 2005, but ongoing permitting issues, weather events, and limited maintenance have contributed to an increasing number of failures and power interruptions. While demand for electricity has remained level, the availability of energy in the form of electricity, natural gas, and oil will become a greater challenge after 2020 as the population increases. Although about 17,000 miles of additional high-voltage transmission lines and significant oil and gas pipelines are planned over the next five years, permitting and siting issues threaten their completion.

The main sectors of energy consumption in the United States are electric power generation, which is the largest at 40 percent of the total, followed by transportation at 28 percent, industry at 20 percent, and residential at 11 percent. The primary sources of fuel used to create this energy are petroleum, natural gas, and coal, although the fuel source mix is continually evolving.

What should engineers be doing?

- Help the grid respond to an evolving mix of energy sources, including renewables, and incorporate new technologies that can lower overall energy use such as smart meters. Consider new approaches to permitting and building transmission lines in the context of sustainability.
- Prepare to add to the network by building and permitting new energy generation facilities, considering that new transmission lines will be needed to move energy from new sources to where it's needed.
- Strengthen the grid by addressing the resilience of the operation and planning of the bulk power system, such as real-time transmission operations, balancing load and generation, emergency operation, systems restoration, voltage control, and cyber security.

Case Study: Texas Competitive Renewable Energy Zone

Texas is one of the few areas of the country where having enough energy capacity is expected to be an issue in the near term. Texas also wanted to ensure that renewable energy sources were a major part of the resource mix for adding capacity. As a result, they developed the Texas Competitive Renewable Energy Zone (CREZ).

© ASCE 2014

The CREZ program is a Public Utilities Commission of Texas (PUCT) inspired enterprise to deliver 18,500 megawatts of west Texas wind generation to markets within the Electric Reliability Council of Texas (ERCOT).

The project deadline required an ambitious schedule. Crews set 556 steel poles across three counties in six months along a 90-mile right-of-way in North Texas, the longest section of transmission line included in the CREZ program. The siting of the transmission lines also requires complex permitting and construction. For example:

- Approximately 117 rights-of-way were acquired for the Clear Crossing — Dermott transmission line, one of seven transmission lines that are part of the program.
- The anchor bolt foundations for the poles, which stand 600–800 feet apart, required 8,850 cubic yards of concrete.
- To connect the Clear Crossing and Dermott stations, about 1,080 miles of cable coiled on 540 spools will be needed.

With an ambitious regional plan and successful project delivery, Texas is taking steps to ensure it will be ready for the future.

Case Study: Sunrise Powerlink Transmission Line

The San Diego region is prone to brownouts and blackouts as summer heat waves strain the electric grid. To address the need for additional transmission and greater reliability, San Diego Gas & Electric (SDG&E) completed the Sunrise Powerlink in 2012, a 500,000-volt transmission line linking San Diego to the Imperial Valley, one of the most renewable-rich regions in California.

What made this project so unique and innovative? The project included 18 months of construction that encompassed both overhead and underground technology as well as different climates and rough, remote terrain. For environmental reasons, nearly 75 percent of the construction was performed by helicopters, and the project logged more than 30,000 flight hours. In addition, the Sunrise Powerlink was the subject of a five-year regulatory review considered to be the most comprehensive study of a proposed transmission power line in state history.

The transmission line will eventually carry 1,000 megawatts of power, or enough energy to serve 650,000 homes. This includes a significant amount of wind and solar power. By 2020, 33 percent of SDG&E's power will be derived from renewable resources.

Transportation

Over two hundred million trips are taken daily across deficient bridges in the nation's 102 largest metropolitan regions. In total, one in nine of the nation's bridges are rated as structurally deficient, while the average age of the nation's 607,380 bridges is

© ASCE 2014

currently 42 years. The Federal Highway Administration (FHWA) estimates that to eliminate the nation's bridge backlog by 2028, we would need to invest $20.5 billion annually, while only $12.8 billion is being spent currently. In addition, forty-two percent of America's major urban highways remain congested, costing the economy an estimated $101 billion in wasted time and fuel annually.

Transit systems have increased in popularity as a younger generation demands more transportation choices. However, the transit system is not comprehensive, as 45% of American households lack any access to transit, and millions more have inadequate service levels. Americans who do have access have increased their ridership 9.1% in the past decade, and that trend is expected to continue. Although investment in transit has also increased, deficient and deteriorating transit systems cost the U.S. economy $90 billion in 2010, as many transit agencies are struggling to maintain aging and obsolete fleets and facilities amid an economic downturn that has reduced their funding, forcing service cuts and fare increases. With projected population growth comes a huge increase in demand for transportation, for both passengers and goods.

What should engineers be doing?

- Develop transportation infrastructure concepts with a mix of travel options, pedestrian and bicycle thoroughfares, and efficient traffic flow.
- Actively contribute to planning, designing, and building new infrastructure as well as improving existing infrastructure. Focus on eliminating bottlenecks, upgrading traffic control technology and detection technology, and supporting new systems that allow large passenger volumes on interregional routes.
- Design intelligent transportation systems (ITS) to enhance the efficiency, speed, and reliability of public and private transport.

Case Study: Oregon Bridge Delivery Program

In 2003 the Oregon Legislature placed an increased priority on the state's bridge program with the Oregon Transportation Investment Act. At the time, the state estimated that deteriorating bridges could cost Oregon's economy $123 billion in lost production and 88,000 lost jobs over the next 25 years. The legislation included the State Bridge Delivery Program, a ten-year, $1.3 billion program that set out to repair and replace hundreds of bridges across the state, thereby ensuring the unrestricted movement of freight and spurring economic growth.

The program employed the context sensitive and sustainable solutions philosophy throughout the process, incorporating activities that foster workforce growth and development; reflect the community's interests; maintain mobility and safety; ensure sound stewardship of the natural environment; and promote cost-effective decision making.

© ASCE 2014

Case Study: I-81 Pavement Recycling

Combining cold in-place recycling, cold central-plant recycling, and full-depth reclamation made a 3.7 mile section of Virginia's I-81 the first highway reconstruction project in the United States to use all three environmentally sustainable methods together. The rehabilitated section of pavement was 43 years old, well past its intended design life, and had seen heavier volumes of truck traffic than it had originally been engineered for.

The $10.1 million project reused existing materials from the underlying road structure, while the driving surface received a new overlay of asphalt. The road construction method was not only environmentally sustainable — it reduced construction time by about two-thirds and saved the Commonwealth of Virginia millions, compared to the cost of conventional reconstruction. Traditional pavement construction would have required building another travel lane and would have taken one to two years to complete. By using in-place recycling, the project time was cut to seven months, resulting in significant cost savings, and reduced traffic disruptions.

By recycling pavement on-site, truck usage to haul in materials was minimized, greatly reducing fuel consumption. Additionally, the reliance on a novel traffic-management plan kept other vehicles moving through, and around, the interstate work zone without a major incident.

Conclusion

Infrastructure is the foundation that connects the nation's businesses, communities, and people, driving our economy and improving our quality of life. For the U.S. economy to be the most competitive in the world, we need a first class infrastructure system – transport systems that move people and goods efficiently and at reasonable cost by land, water, and air; transmission systems that deliver reliable, low-cost power from a wide range of energy sources; and water systems that drive industrial processes as well as the daily functions in our homes. Yet today, our infrastructure systems are failing to keep pace with the current and expanding needs, and investment in infrastructure is faltering. We also need to seize the opportunity to find sustainable solutions to these challenges.

We must commit today to make our vision of the future a reality – an American infrastructure system that is sustainable and the source of our prosperity.

© ASCE 2014

References

ASCE Committee on America's Infrastructure (2013), *2013 Report Card for America's Infrastructure,* www.infrastructurereportcard.org

EDR Group & the American Society of Civil Engineers (2011), *Failure to Act: The Economic Impact of Current Investment Trends in Surface Transportation Infrastructure*, www.asce.org/failuretoact

© ASCE 2014

Transformational Changes Associated with Sustainable Stormwater Management Practices in Onondaga County, New York

Carli Flynn[1], Cliff I. Davidson[1], and Joanne Mahoney[2]

[1] Department of Civil and Environmental Engineering and Syracuse Center of Excellence, Syracuse University, 151 Link Hall, Syracuse, NY 13224; email: cflynn@syr.edu, davidson@syr.edu
[2] Office of the County Executive, Onondaga County, 421 Montgomery Street, 14th Floor, Syracuse, NY 13202

ABSTRACT: Green infrastructure technologies (GI) are becoming a popular decentralized approach to stormwater management and are commonly recognized as a key component of building sustainable urban water systems. While many U.S. municipalities have encountered barriers to implementing GI, Onondaga County has integrated numerous GI technologies through their "Save the Rain" Program into previously unpopular stormwater management plans in only a few years. This paper investigates the sociopolitical and environmental factors that influenced the adoption of GI technologies in Onondaga County. The primary factors include the formation of a policy entrepreneurship coalition, the acceptance of GI as an effective stormwater management practice, and economic opportunities which reduced financial barriers for GI projects. The findings are based on interviews with local leaders and experts, and review of documents and media coverage related to Onondaga County's evolving stormwater management plans. Transformational changes related to these plans such as ecological regime shifts and adaptive governance strategies are analyzed.

INTRODUCTION

Most municipal stormwater control plans in the U.S. stem from policies which favor the use of gray infrastructure, or technologies that either enhance or supplement existing sewer infrastructure. These engineering solutions tend to be large in scale, can take years or decades to complete, and are often costly. Alternatively, GI, also known as low impact design technologies, are designed to protect or restore the natural hydrology of a site, capturing stormwater volume through the use of soils, vegetation, and engineered systems that mimic nature. Integrating GI into urban stormwater management planning represents an introduction of a new and more sustainable paradigm in urban stormwater management.

Social-ecological systems (SES) are dynamic systems that co-evolve through interactions between actors, institutions, and resources within a given social-

© ASCE 2014

ecological setting (Berkes and Folke, 1998; Gunderson, 2001). The Onondaga Lake Watershed in Onondaga County, NY, is an example of an urban water SES that has experienced several regime shifts over the past century, due in part to changes in Onondaga County's stormwater management practices. Onondaga Lake was previously referred to as the most polluted lake in America due to a century of industrial contamination, proportionally high inflows of treated municipal wastewater discharges, and combined sewer overflows (CSOs). Historically, Onondaga County's stormwater management plans included only gray infrastructure technologies. These plans changed considerably in 2009 with GI replacing many planned gray infrastructure projects.

This paper explores the most important factors enabling Onondaga County to become a national leader in implementing a GI strategies, in particular how political will, the incorporation of knowledge and interests of stakeholders and the right economic opportunities helped to bring about more effective and sustainable stormwater management plans. These changes in Onondaga County's plans and the related SES outcomes can be understood through a resilience theory perspective; specifically, the regime shifts and adaptive governance strategies related to the Onondaga Lake SES are analyzed.

BACKGROUND

Past Stormwater Management Practices in Onondaga County

Like most urban regions in the Northeast U.S., the city of Syracuse in Onondaga County operates a combined sewer system. During dry weather, sanitary sewage is carried to the Syracuse Metropolitan Wastewater Treatment Plant (METRO), and treated effluents are discharged into Onondaga Lake. The contribution of METRO effluent to total inflow for Onondaga Lake is the largest for a lake in the United States, representing approximately 25% of the total inflow on an average basis (Effler et al., 2013). CSO discharges occur during rain events as small as 0.10-0.15 in/hour in some areas, resulting in the overflow of untreated sanitary sewage and stormwater to the tributaries of the lake (Coon and Reddy, 2008).

In 1988, the Atlantic States Legal Foundation (ASLF), a small non-profit in Syracuse, filed a lawsuit against Onondaga County, alleging that the discharges from METRO and CSOs were violating state and federal water quality laws. Then in 1989, Onondaga County entered into a Judgment of Consent, requiring the County to execute a series of studies to evaluate compliance plans. Negotiations ensued until an Amended Consent Judgment (ACJ) was executed in January 1998. By this time, the County had implemented several traditional gray infrastructure projects that captured or eliminated about 74% of the total annual CSO volume of 3.92 billion gallons per year. The ACJ required Onondaga County to increase the annual CSO volume captured to 85%, remove additional floatable waste, reach higher water quality standards for bacteria in the lake and achieve tighter ammonia and phosphorus discharge standards for METRO by 2012.

Decades of increasing environmental damage to Onondaga Lake and its tributaries deepened the vested interest in stormwater management plans held by local stakeholders. While all major regulating and regulated parties were directly involved

© ASCE 2014

in the ACJ project planning, several important community groups were not. Over time, this lack of involvement led many stakeholders to become increasingly opposed to the expensive and invasive gray infrastructure projects. The environmental injustice stemming from this exclusion was particularly evident to two key stakeholders: the Onondaga Nation and the residents of the Southside neighborhood of Syracuse (Perreault et al., 2012).

Onondaga Lake is considered a sacred site by the Onondaga people. On the shores of Onondaga Lake, the Peacemaker brought together five nations to form the Haudenosaunee under the Great Law of Peace (or *Gayanashagowa*) over 1000 years ago. The Onondaga Nation remains committed to fulfilling the mandates of the Great Law of Peace, including its vision of environmental stewardship and cooperative resource management. In March 2005, a Land Rights Action was filed by the Onondaga Nation, seeking the freedom to exercise their responsibility to the land and to "bring about a healing between themselves and all others who live in this region." The land rights claim was dismissed in 2013 and no formal recognition of these traditional rights has been made; however, this action reaffirmed Onondaga Nation's role a primary stakeholder in promoting the health of the Onondaga Lake ecosystem.

Of the gray infrastructure technologies included in the 1998 ACJ projects, the regional treatment facilities (RTFs) were met with the highest level of public protest. One of the planned RTFs, known as the Midland RTF, was to be built in the Southside neighborhood of Syracuse due to its proximity to Onondaga Creek, a main tributary of Onondaga Lake. Many Southside residents already experienced intrusive infrastructure developments, such as an expansion project for a nearby hospital which displaced many residents, and a garbage incinerating plant which further added to poor air quality issues in the area (Tauxe, 2011). The Partnership for Onondaga Creek (POC), a local nonprofit, formed in response to the perceived injustices that the Midland RTF would bring to the residents of the Southside neighborhood.

In 2001, the Syracuse Common Council voted unanimously against selling city land to Onondaga County for the Midland RTF. A federal district judge ordered the City of Syracuse and Onondaga County to work out their differences through negotiations, but this time to include community stakeholders. Within these negotiations, the POC presented alternative solutions to RTFs, such as underground storage, and began to collaborate with the ASLF and Onondaga Nation. This cross-cultural alliance proved to be an effective social network for the promotion of GI in Onondaga County (Tauxe, 2011). However, the longstanding relationships between Onondaga County and select engineering firms favored the original gray infrastructure projects such as the RTFs. Ultimately, the Syracuse City land was sold to Onondaga County and construction began on the Midland RTF, including an additional large-scale pipeline.

The Midland RTF construction resulted in several negative impacts on the Southside community, including the eviction of 45 families. The POC filed a Title VI claim of civil rights discrimination to the US EPA, documenting the social damages and injustices due to the construction (Lane and Heath 2007). Public protest eventually halted construction of a large conveyance pipe, leaving the facility to operate at a reduced capacity. An "anti-RTF" sentiment grew throughout Onondaga County along with a lack of trust in the stormwater management decision makers, as

© ASCE 2014

demand for alternative plans surrounding the Midland facility created a strong community awareness of the County's unpopular stormwater management plans.

The case against the RTFs also began to build on scientific evidence, as it was determined that they would not provide a comprehensive solution to Onondaga County's environmental problems despite achieving the desired CSO volume control. In 2007, the Onondaga Environmental Institute (OEI) conducted a study on the potential loading sources of bacteria throughout the Onondaga Lake Watershed. The results showed high levels of bacteria in the tributaries of Onondaga Lake during dry weather, suggesting that there were sources of contamination other than CSOs leading to non-compliance of state standards for bacteria (Hughes, 2008). Since RTFs would only eliminate the bacteria associated with CSOs, they were deemed an inadequate solution to reach compliance with the bacteria standards.

Introduction of GI Stormwater Management Paradigm

Some regions of the US were early adopters of GI technologies, such as the Pacific Northwest in the 1990s. The success of early projects led to a 2006 report by the National Resource Defense Council which stimulated other national groups to promote the use of GI (Kloss et al., 2006). On April 19, 2007, the US EPA released an official statement in support of the use of GI in stormwater management planning. This change in national mindset provided momentum to local stakeholders in Onondaga County to work together to develop stormwater plans which included GI (Knauss, 2010).

Although community support in Onondaga County was growing, little hope existed for GI to become a reality under the pre-existing political leadership. The 2007 election for County Executive was the major impetus for the introduction of GI in Onondaga County. Joanne Mahoney was a local politician who was familiar with the anti-RTF sentiment of local residents and the alternative plans proposed by the POC. In 2005, she met with Oren Lyons, faithkeeper of the Onondaga Nation, and considered the important contributions that the Nation could make towards the County's efforts. When she ran for County Executive in 2007, she turned to the Nation and POC to develop her approach to Onondaga County's stormwater management agenda (Mahoney, 2011). After Joanne Mahoney was elected, she successfully reached out to an even wider array of stakeholders to form a policy entrepreneurship coalition in support of GI.

Shortly after taking office, Joanne Mahoney obtained a moratorium on construction of an RTF that was to be built in downtown Syracuse. Several committees were created with representatives from the Onondaga Nation, POC, ASLF, and other formerly excluded stakeholder groups in order to evaluate alternative stormwater management plans. The findings from these committees were incorporated into a fourth Amended Consent Judgment in November 2009, authorizing Onondaga County to use both gray infrastructure and GI in its stormwater management plans. Previously, several municipalities throughout the US had integrated GI into consent decrees as supplemental environmental projects. However, Onondaga County's ACJ represented the first time in the U.S. that GI was listed as a direct legal requirement in the reduction of CSOs (Garrison and Hobbs, 2011). The agreement specified increasing total CSO volume capture, ultimately reaching 95%

© ASCE 2014

by 2018. Collectively, the new comprehensive stormwater plan for Onondaga County became known as the *Save the Rain* program. While much of the *Save the Rain* program efforts focus on the stormwater mitigation benefits, the program also strives to maximize social benefits through job programs, strategic project placement and funding opportunities. In addition to public projects, several efforts have focused on commercial and residential programs which promote the use of GI.

The rapid development of GI projects throughout the County would not have been possible without economic opportunities that made GI cost effective against gray infrastructure alternatives. Before GI was considered as a viable strategy, the alternative gray technologies proposed by the POC and other stakeholders were repeatedly turned down due to the ACJ stipulation of cost effectiveness. Cost estimate bids for the gray infrastructure options fluctuated for many years, with the low bid cost of the RTFs appearing favorable to more costly bids for underground water storage (Lane, 2011). The 2009 ACJ plans were attractive not only because they were less intrusive to surrounding communities, but also because they were expected to save Onondaga County more than $20 million.

In New York State, the Clean Water Act's State Revolving Loan Fund (SRF) program, administered by the Environmental Facilities Corporation (EFC), provides funding for stormwater management projects. Of the overall *Save the Rain* budget, the majority of funds are financed through county bond debt, which will be serviced through increased sewer use charges. Additional funding will come from federal and state assistance, including SRF loans and grants. Gray infrastructure project funding will likely be secured through the SRF, but funding GI requires a more complicated loan and bond process. Because GI projects have difficulty fitting into EFC's standard review and approval processes, it is administratively and financially inefficient for the EFC to verify GI investments on a project-by-project basis. Thus, Onondaga County does not rely on the EFC to fund the upfront costs of GI initiatives. Instead, the County has used capital funds and independently-secured debt to finance the implementation and installation of GI projects. Once GI projects are installed, County officials plan to bundle sets of completed projects and seek EFC approval to refinance original debt though the SRF and other EFC long term loans. Although this two-step financing is cumbersome, County officials expect that the EFC will more readily approve bundled GI projects when exact costs have been established and effectiveness proven (Millea, 2011).

ANALYSIS

Adaptive Governance Strategies

There are several frameworks that enable governments to manage complex ecosystems. Adaptive management refers to the continual change in management practices following improved understanding of the system's behavior, with an emphasis on knowledge and involvement of stakeholders (Webb and Bodin, 2008). Adaptive comanagement combines the dynamic learning characteristic of adaptive management with the multilevel linkage characteristic of comanagement, including features like sharing of management power and responsibility, and linking institutions and organizations (Folke et al., 2005). The term "adaptive governance" has also been

© ASCE 2014

used to convey the difficulty of control within complex SESs, the need to proceed in the face of uncertainty, and the importance of dealing with diverse values, interests and perspectives among constituents (Dietz et al., 2003). Folke et al. (2005) describe four interacting aspects of importance in adaptive governance of complex SESs.

1. Build knowledge of ecosystem dynamics

Several long term monitoring efforts have existed to collect data on the Onondaga Lake watershed, some of which are commissioned by Onondaga County. The Upstate Freshwater Institute in Syracuse has studied the aquatic ecology and water quality of Onondaga Lake, including long-term data on indicators like nitrogen and phosphorus since 1981. Also, the 2007 OEI study on bacteria loadings from aging sewer infrastructure provided an impetus for the County to consider management solutions beyond RTFs.

2. Make continuous use of ecological knowledge

The 1998 ACJ initiated the Ambient Monitoring Program, and beginning in 2000, regulating parties and partner organizations were to meet every two years to discuss changes to enhance and clarify the monitoring program. An "Environmental Monitor" was appointed to oversee monitoring efforts. The 2009 ACJ set up additional monitoring efforts, where new data are used to evaluate and modify the model for total maximum daily load (TMDL) processes for phosphorus effluent from the treatment plant. An annual report is required, including CSO monitoring data, post-construction monitoring, and annual Stormwater Management Model (SWMM) updates. Results from the SWMM model are used by the NYDEC to determine compliance.

3. Support flexible institutions and multilevel governance systems

Adaptive governance is operationalized though adaptive comanagement in the sharing of management power and responsibility. The *Save the Rain* program built a collaborative environment between the Onondaga County government, the Syracuse City government, private businesses and County residents. Project permissions and maintenance programs have been established between the County and City. There is also a sharing of responsibility with private businesses and NGOs, and with the residents of Onondaga County through outreach programs.

The partnerships between the County and City governments, the Onondaga Nation, POC, ASLF, OEI and others were invaluable to the development of new stormwater management plans. These types of social networks with ties between groups of stakeholders support the generation of knowledge and novel solutions to complex problems (Hahn et al., 2008). Another important factor was the integration of scientific data with traditional ecological knowledge, or the "cumulative body of knowledge, practice and belief concerning the relationships of living beings to one another and to the physical environment" (Berkes, 2012). The 2005 Land Rights Act defined the "unique spiritual, cultural, and historic relationship with the land" held by the Onondaga Nation and its people, as well as the long-term strategy of the Nation "to promote conservation, environmental protection and responsible economic development in partnership with its neighbors." This knowledge and environmental

© ASCE 2014

stewardship was integrated into stormwater management plans during the 2008 planning committees.

4. Cope with external perturbations, uncertainty and surprise

The last of the adaptive governance features focuses on the resilience of an SES and its ability to utilize disturbances as opportunities to transform into more desired states rather than degrade the current state. For decades, little information flowed between the County government and local stakeholders, thus reducing the response diversity and adaptive capacity of the Onondaga Lake SES. However, the recent changes in management strategies suggest an increase in resilience. The social networks that built upon visions and knowledge of the lake's ecosystem dynamics is one source of increased SES resilience (Hahn et al., 2008). The GI projects adopted under the *Save the Rain* program have also increased the resilience of the Onondaga Lake SES, as GI can influence ecosystem health by contributing to ecosystem resilience (Tzoulas et al., 2007). Finally, while an undesired regime shift in an ecosystem may indicate that it has lost resilience, actors with the capacity to respond to change can restore it to a desired state; thus, the SES is still resilient (Bodin and Norberg, 2005).

Regime Shifts

A regime is defined as a self-reinforcing state of attraction within a system which is controlled by multiple inherent feedback processes, and external forces and internal processes can cause systems to shift towards a different regime (Norberg et al., 2008; Scheffer and Carpenter, 2003). Historically, urban watershed management innovations have been shown to bring about regime shifts in SESs, such as a reduction in water borne illness and eutrophic states of receiving waters. The development of urban stormwater and wastewater management strategies has cycled from decentralized privy vault-cesspool systems to centralized conveyance management throughout the 19th and 20th centuries, and more recently back to a renewed interest in decentralized management alternatives such as GI. Many factors have contributed to these shifts, such as cost of available technologies, accepted scientific theories, and the prevailing opinions on sanitation (Burian et al., 2000).

By the late 19th century, large cities in the US commonly built combined sewer systems that discharged into local water bodies. The rationale that engineers of the time used to build thousands of miles of combined sewer systems throughout the US left a heritage of water pollution problems that policy-makers continue to deal with today (Tarr, 1979). Tarr and McMichael (1977) identify three turning points in early stormwater and wastewater management history that were especially important: the replacement of cesspools and privy vaults by sewers, the debate over whether to construct separate or combined sewers, and the decision to discharge sewage into surface waters, leaving treatment to both natural purification in the receiving water and filtration by subsequent water users. These turning points are reflected in the significant changes of Onondaga County's stormwater and wastewater management strategies. Six urban watershed management strategy regimes defined by these and other major turning points in the Onondaga Lake SES are summarized in Table 1.

© ASCE 2014

Table 1: Onondaga Lake SES Management Regimes

Regime	Year	Stormwater and Wastewater Management Changes
1	Pre 1896	Increasing urbanization with uncontrolled wastewater and stormwater management
2	1896	Combined sewer system built
3	1960	Central treatment plant completed
4	1979	Treatment plant upgraded to tertiary treatment
5	1998	First ACJ with gray infrastructure projects and METRO upgrades
6	2009	4^{th} ACJ passed to utilize GI

Human activities often lead to associated regime shifts in ecosystems (Scheffer et al., 2001). The evolving stormwater and wastewater management plans of Onondaga County are linked to several ecological regime shifts in the Onondaga Lake SES. This is primarily due to the large contribution of municipal effluent to the lake's water balance. Before recent upgrades, the effluent from METRO was found to contribute 60% of the phosphorus and 90% of the ammonia loadings to the lake, leading to a hypereutrophic state with high populations of phytoplankton, increased turbidity, extended periods of hypolimnetic anoxia and a decrease in ecosystem function (Canale and Effler, 1989).

Phosphorus is a primary driver for the environmental degradation in Onondaga Lake associated with municipal waste inputs from METRO. Figure 1 shows the

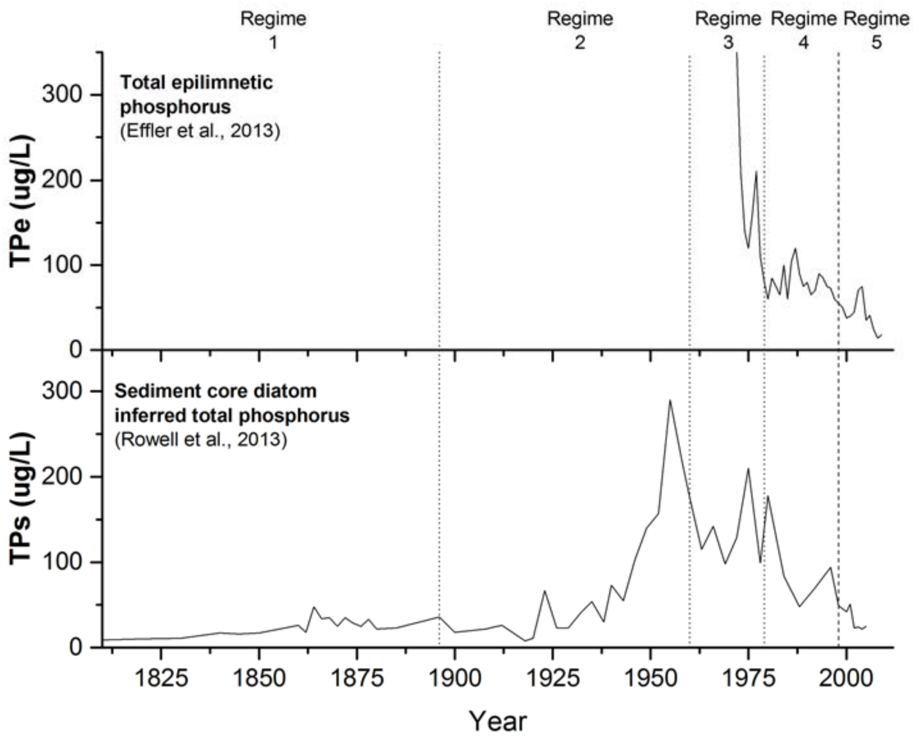


Figure 1: (Top) Measured summer epilimnetic total phosphorous concentrations in Onondaga Lake, modified from Effler et al., 2013; and (bottom) inferred historic phosphorus concentrations in the Lake, modified from Rowell et al. (2013), for watershed management regimes 1-5.

© ASCE 2014

fluctuating levels of phosphorus in Onondaga Lake through the first five stormwater and wastewater management regimes identified in Table 1. The top portion of the figure is reconstructed from long term phosphorus monitoring by the Upstate Freshwater Institute, while the bottom portion is derived from sediment coring efforts to develop a proxy for historical phosphorus levels in Onondaga Lake. The general trends in Regimes 3, 4 and 5 are clear between the two data sets, as phosphorus levels decrease with increasingly advanced stormwater and wastewater management regimes. Another important turning point is the banning of phosphates from laundry detergents, which also occurred toward the end of Regime 3 in 1971 and thus enhances the decreasing trends seen in Regimes 3 and 4. The 1998 ACJ set a requirement for the average epilimnetic phosphorus concentrations in Onondaga Lake of less than 20 µg P/L. Further systematic reductions in loading to the lake's upper layers will be necessary to ensure meeting the goal (Effler et al. 2013).

Drastic changes in lake ecological regimes due to municipal and industrial waste inputs also led to socioeconomic shifts. In the early half of the 20th century, the thriving fisheries and resort industries that had operated since the 1800s slowly died out as the lake's water quality deteriorated (Thompson, 2002). The commercial cold-water fishery was eliminated by the late 1800s, the lake was closed to ice harvesting in 1901, swimming was banned in 1940 due to elevated bacteria counts and poor water clarity, and all fishing was banned in1972 due to mercury contamination (Effler et al., 2010; Landers, 2006).

The 2009 ACJ represents a turning point with potential to bring about a sixth regime for the Onondaga Lake SES, in which GI assists in the recovery of the Lake through enhanced nonpoint source pollution control. Figure 2 summarizes the progress made since the 1998 ACJ in reducing the number of CSO points without abatement strategies, and consequently increasing the annual percent capture of CSO volume. A CSO point with an abatement strategy does not imply that all CSO volume will be captured at each outfall point, and performance, especially for GI abatement strategies, may vary depending on the strategies or technologies used and different conditions present from year to year. However, increasing annual CSO volume capture with increased abatement strategies will likely accelerate Lake's recovery.

In the past two decades of cleanup efforts, Onondaga Lake has begun to shift back to its preindustrial regime, as water quality and clarity continue to improve. Since 2008, no algal blooms have been evident; total phosphorus concentrations were below the state's guidance value for recreational use; macrophyte communities have become more diverse; populations of gamefish have continued to increase steadily; and bacteria counts remained within limits for water recreation (EcoLogic, LLC et al., 2010; Upstate Freshwater Institute et al., 2014).

CONCLUSIONS

Onondaga County's *Save the Rain* program has received national recognition. In 2010, the EPA awarded the County Executive, Onondaga Nation, POC and ASLF the Environmental Quality Award. One year later, the EPA named Onondaga County one of 10 U.S. partner communities in their new strategic GI agenda, which outlines the activities that the EPA will undertake to help communities implement GI. In 2013, the program received six major awards, including the U.S. Water Prize and the New

© ASCE 2014

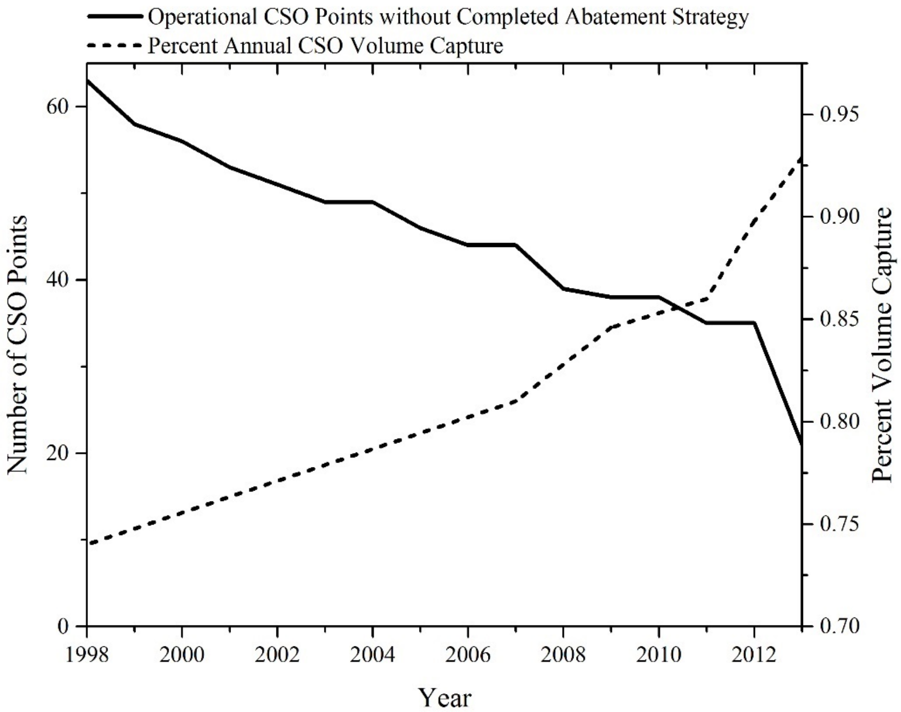


Figure 2: Number of operational CSO points without abatement strategies and total percent capture of annual CSO volume. Note that the original system had over 90 operational CSO points. Data from annual ACJ reports such as OCDWEP (2014).

York State Environmental Excellence Award, the highest environmental award at the state level.

The positive ecological changes in the Onondaga Lake watershed are a reflection of key changes within the governance system of Onondaga County's stormwater management plans. The shift in the management strategies from solely gray infrastructure to the incorporation of GI would have been highly unlikely if it were not for the changes in the political and economic settings, as well as supportive leadership at the local level. Furthermore, the adoption of GI in Onondaga County encompasses social changes in addition to environmental restoration. The Onondaga Nation has continued to define its role as one of the caretakers of Onondaga Lake, as the Nation released its "Vision for a Clean Onondaga Lake" in 2010, describing holistic, watershed focused goals for restoration. The County Executive acknowledges the need for broader sets of goals "beyond ACJ requirements," and the potential social benefits that GI can bring about such as community development and job creation (Mahoney, 2011).

ACKNOWLEDGMENTS

We thank the SURDNA Foundation for providing funding for this work, as well as all Onondaga Lake resource users with whom we interacted in this work, including Steve Effler, Joseph Heath, Aggie Lane, Dave Matthews, Ed Michalenko, Matthew Millea, Chandler Rowell, Lindsay Speer, and Mallory Squier.

© ASCE 2014

REFERENCES

Berkes, F., 2012. Sacred Ecology, 3rd ed. Routledge, New York.
Berkes, F., Folke, C., 1998. Linking social and ecological systems for resilience and sustainability, in: Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. pp. 13–20.
Bodin, Ö., Norberg, J., 2005. Information network topologies for enhanced local adaptive management. Environmental Management 35, 175–193.
Burian, S.J., Nix, S.J., Pitt, R.E., Durrans, S.R., 2000. Urban wastewater management in the United States: Past, present, and future. Journal of Urban Technology 7, 33–62.
Canale, R.P., Effler, S.W., 1989. Stochastic phosphorous model for Onondaga Lake. Water Research 23, 1009–1016.
Coon, W.F., Reddy, J.E., 2008. Hydrologic and water-quality characterization and modeling of the Onondaga Lake Basin, Onondaga County, New York. US Geological Survey.
Dietz, T., Ostrom, E., Stern, P.C., 2003. The struggle to govern the commons. Science 302, 1907–1912.
EcoLogic, LLC, Anchor QEA, Onondaga County Dept of Water Environment Protection, Rudstam, L., Walker, W.W., 2010. Onondaga Lake Ambient Monitoring Program 2008 Final Report. Onondaga County Department of Water Environment Protection, Onondaga County, NY.
Effler, S.W., O'Donnell, S.M., Prestigiacomo, A.R., Matthews, D.A., Auer, M.T., 2013. Retrospective analyses of inputs of municipal wastewater effluent and coupled impacts on an urban lake. Water Environment Research 85, 13–26.
Effler, S.W., O'Donnell, S.M., Prestigiacomo, A.R., O'Donnell, D.M., Gelda, R.K., Matthews, D.A., 2010. The effect of municipal wastewater effluent on nitrogen levels in Onondaga Lake, a 36-year record. Water Environment Research 82, 3–19.
Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. Adaptive governance of social-ecological systems. Annu. Rev. Environ. Resour. 30, 441–473.
Garrison, N., Hobbs, K., 2011. Rooftops to Rivers II: Green strategies for controlling stormwater and combined sewer overflows. Natural Resources Defense Council, Washington D.C.
Gunderson, L.H., 2001. Panarchy: understanding transformations in human and natural systems. Island Press, Washington D.C.
Hahn, T., Schultz, L., Folke, C., Olsson, P., 2008. Social networks as sources of resilience in social–ecological systems, in: Complexity Theory for a Sustainable Future. Columbia University Press, New York, NY, pp. 119–48.
Hughes, D.J., 2008. An Analysis of Onondaga County Bacteria Monitoring Data. Onondaga Environmental Institute, Syracuse, NY.
Kloss, C., Calarusse, C., Stoner, N., 2006. Rooftops to rivers: Green strategies for controlling stormwater and combined sewer overflows. Natural Resources Defense Council, Washington D.C.
Knauss, T., 2010. Activists' persistence on sewage pushed Onondaga County to "go green". The Syracuse Post Standard.
Landers, J., 2006. New Life for Onondaga Lake. Civil Engineering 76, 64–71, 86.

© ASCE 2014

Lane, A., 2011. Personal communication.

Lane, A., Heath, T., 2007. Environmental Racism in Syracuse, NY: A Case Study of Government's Failure to Protect an Endangered Waterway and a Neglected Community. Partnership for Onondaga Creek, Syracuse, NY.

Mahoney, J., 2011. Personal communication.

Millea, M., 2011. Personal communication.

Norberg, J., Wilson, J., Walker, B., Ostrom, E., 2008. Diversity and resilience of social-ecological systems, in: Complexity Theory for a Sustainable Future. Columbia University Press, New York, NY, pp. 46–79.

Onondaga County Department of Water Environment Protection (OCDWEP), 2014. Onondaga County, NY ACJ Fourth Stipulation 2013 Annual Report, Onondaga County, NY.

Perreault, T., Wraight, S., Perreault, M., 2012. Environmental injustice in the Onondaga lake waterscape, New York State, USA. Water Alternatives 5, 485–506.

Rowell, C.H., Bloomfield, J.A., Enache, M., Quinlan, R., Perkins, M., Effler, S.W., Charles, D.F., Smith, A.J., Ababneh, L., 2013. Environmental Ensemble Modeling: A Complimentary Approach to Understanding Past Water Quality Conditions. New York State Department of Environmental Conservation.

Scheffer, M., Carpenter, S., Foley, J.A., Folke, C., Walker, B., 2001. Catastrophic shifts in ecosystems. Nature 413, 591–596.

Scheffer, M., Carpenter, S.R., 2003. Catastrophic regime shifts in ecosystems: linking theory to observation. Trends in ecology & evolution 18, 648–656.

Tarr, J.A., 1979. The separate vs. combined sewer problem: a case study in urban technology design choice. J Urban Hist 5, 308–339.

Tarr, J.A., McMichael, F.C., 1977. Historic turning points in municipal water supply and wastewater disposal, 1850-1932. Civil Engineering—ASCE 47, 82–86.

Tauxe, C., 2011. Onondaga Lake Cleanup: A Case Study of Environmental Conflict & Cross-Cultural Coalition. Peace Studies Journal 4.

Thompson, D.H., 2002. The Golden Age of Onondaga Lake Resorts, 1st ed. Purple Mountain Pr Ltd, Fleischmanns, N.Y.

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., James, P., 2007. Promoting ecosystem and human health in urban areas using green infrastructure: a literature review. Landscape and urban planning 81, 167–178.

Upstate Freshwater Institute, Anchor QEA, Onondaga County Dept of Water Environment Protection, Rudstam, L., Walker, W.W., 2014. Onondaga Lake Ambient Monitoring Program: 2012. Onondaga County Dept. of Water Environment Protection, Onondaga County, NY.

Webb, C., Bodin, Ö., 2008. A network perspective on modularity and control of flow in robust systems, in: Complexity Theory for a Sustainable Future. Columbia University Press, New York, NY, pp. 85–118.

© ASCE 2014

Water Operator Twinning Partnership between Palm Beach County Water Utilities Department and Manila Water Concessionaires on Planning for Climate Change Impacts

Maurice Tobon, P.E.[1], and David Yates[2]

[1]Palm Beach County Water Utilities, 8100 Forest Hill Blvd, West Palm Beach, Florida 330413, (561) 493-6003, mtobon@pbcwater.com
[2] National Center for Atmospheric Research, Boulder, Colorado, P.O. Box 3000. Boulder, CO 80307-3000

I. INTRODUCTION

In 2011, the United States Agency for International Development (USAID) through its Environmental Cooperation – Asia (ECO-Asia) project and Waterlinks, a non-profit that promotes and supports water operator partnerships in Asia and the Pacific, facilitated a twinning partnership between MWSS (Metropolitan Waterworks and Sewerage System), Manila Water, Maynilad and Palm Beach/NCAR.

In 2011, the Philippines ranked third globally among countries most vulnerable to disaster risks and natural hazards linked to climate change[1]. Its location along the western part of the Pacific Ocean makes it highly susceptible to monsoons, thunderstorms, and typhoons while its archipelagic nature increases its exposure to storm surges and sea level changes. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) estimates that by 2020, North and Central Luzon and Mindanao will have up to 14 percent less rain while Southern Luzon and parts of the Visayas will experience up to 10 percent more rainfall, indicating intensifying storms, shortened rainy seasons and extended dry seasons[2].The Office of the President has also issued a National Framework on Climate Change for 2010 through 2022, with a vision of developing a "climate resilient Philippines," with adapting to the impacts of climate change as a key pillar.

These increasing climate change-related conditions are likely to aggravate the delivery of basic services to residents in cities and towns throughout the country, where already more than 25 million urban residents presently lack access to water supply and sustainable sanitation. Potential impacts such as fresh water shortages due to drought conditions, water quality degradation, extreme rainfall and associated floods, and sea water intrusion from rising sea levels could further disrupt services that affect the lives and livelihoods of urban inhabitants.

---

[1]"World Risk Report 2011" by the United Nations University Institute for Environment and Human Security (UNU-EHS), in collaboration with the Bündnis Entwicklung Hilft (Alliance Development Works).

[2]"Potential Impacts of Climate Change on Water Supply and Sanitation" by Dr. Florencia B. Pulhin (2011) (unpublished paper)

© ASCE 2014

Facing challenges in understanding and planning for possible climate-related effects, Philippine water services providers must therefore consider a wide range of factors related to water availability and water quality, population growth, salt water intrusion, probability of extreme weather events and investment potential.

Located in Florida, U.S., and exposed to similar tropical and climatic conditions, the Palm Beach County Water Utilities Department (Palm Beach) has integrated climate change into its future water resource planning process (O'Neil and Yates, 2011). Palm Beach, with technical support from the U.S. National Center for Atmospheric Research (NCAR), has developed a dynamic decision support system for water supply planning in the lower east coast of Florida based on results from the Water Evaluation and Planning System (WEAP) model, an effective tool for aiding water services providers in adapting to climate change impacts (see www.weap21.org; Yates et al., 2005).

To help frame the elements of climate change risk identification, assessment and management and assist with decision-making, Palm Beach has applied the "XLRM framework" (Lempert et al., 2003). XLRM organizes the important elements of deeply uncertain decision analysis. Palm Beach has used these tools in their strategic planning process to evaluate various capital improvement options in light of multiple factors that include changing demand patterns, land use, cost/benefit, and the explicit consideration of climate change (Giles, 2002; Reilly et al., 2001; Schneider et al., 2001).

1.1 Twinning Partnership

Key objectives of the partnership were to (1) increase the awareness and/or understanding of climate change impacts and adaptation measures for MWSS, Manila Water and Maynilad, and (2) introduce innovative tools (WEAP and XLRM) to help strengthen the capacity of the Manila-based services providers to integrate climate change-related risks and factors into their planning processes to build climate resilience.

© ASCE 2014

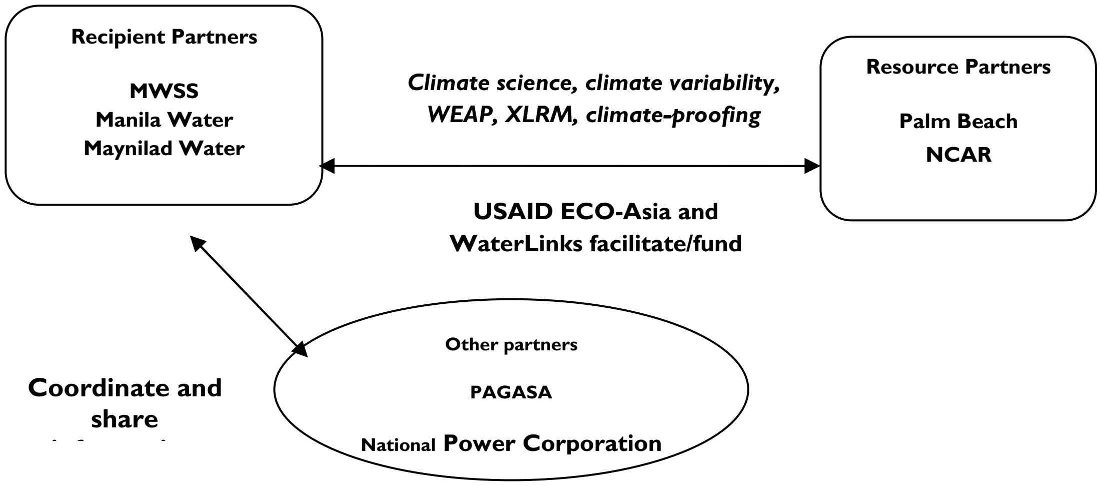


Figure 1. Partnership Arrangement

Through the 18-month partnership, Palm Beach and NCAR worked with their Manila peers to apply WEAP and the XLRM framework and to analyze how climate variability could impact operations and water services delivery. Palm Beach and NCAR provided hands-on training in the U.S. and Manila and offered remote technical support to test tools application and evaluate results (see Table 1) .

Table 1. Twinning Partnership Activities

Date and Location	Activities	Outputs
May 2011 (in Manila)	Introduction to climate change and science by NCAR Climate change adaptation efforts by Manila Water and Maynilad Water Introduction to WEAP and XLRM and short training on application by NCAR Sharing of practical experiences on climate-proofing by Palm Beach Signing of partnership agreement	Partners validated how the partnership could support plans by Manila services providers to address climate change impacts Partners signed formal agreement to cooperate Manila water services providers exposed to basic elements of climate science and variability Manila water services providers familiarized with tools to help improve planning process that includes climate factors
August 2011 (in Manila)	Remote consultation and support by NCAR for WEAP start-up by Manila services providers	Manila water services providers began to collect input data and test the WEAP software with Angat Watershed as model

© ASCE 2014

December 2011 (in Palm Beach)	Technical training on WEAP and XLRM application by NCAR and Palm Beach Technical visit to observe climate-proofing initiatives by Palm Beach	Manila water services providers developed basic simulations and identified challenges, including the need to gather more robust input requirements for the WEAP model Manila water services providers gained in-depth understanding of climate-proofing requirements
February 2012 (in Manila)	Input data collection by Manila services providers through coordination with the PAGASA and the National Electric Commission with remote consultation by NCAR	Manila water services providers recognized the need to work with other relevant agencies to integrate climate aspects Hydrological and climatic data collected for Angat Watershed
May 2012 (in Manila)	Hands-on guidance to update WEAP model by Palm Beach and NCAR Presentation and discussion on lessons/challenges in using the WEAP and recommended solutions at regional workshop on building climate change resilience of water services providers Refresher discussion on XLRM	Manila services providers conducted additional trial simulation runs and made adjustments
August 2012 (in Manila)	Final discussion on progress and lessons learned in the WOP	Manila services providers developed trial WEAP model for Angat Watershed for further improvements

2. PARTNERSHIP ACTIVITY

The twinning partnership followed a decision framework that focused on identifying vulnerabilities and response options. Since projections of many important climate parameters remained deeply uncertain, traditional risk analysis methods were likely to lead to over-confidence or suffered from a lack of the most relevant data.

© ASCE 2014

2.1 Introduction to WEAP

The WEAP model is an integrated water resources planning tool for representing current water conditions in a given area and to explore a wide range of demand and supply options for balancing environment and development objectives. WEAP is widely used to support collaborative water resources planning by providing a common analytical and data management framework to engage stakeholders and decision-makers in an open planning process.

WEAP is a highly graphical, computer based quantitative simulation tool for integrated water resources planning that provides a comprehensive, flexible and user-friendly framework for water policy analysis. WEAP facilitates water simulation, forecasting, and policy analysis by tracking, for example, water demand, supply, runoff, streamflow, storage, pollution generation, treatment and discharge, and instream water quality to help evaluate the full range of water development and management options, and takes account of multiple and competing uses of water systems (Yates et al., 2005; 2009).

2.2 Introduction to XLRM

To help frame the elements of climate change risk identification, assessment and management, the partnership included training and elicitation using a framework known as "XLRM" (Lempert et al., 2003). XLRM organizes the important elements of deeply uncertain decision analysis like climate change by grouping them into four different categories:

- **Exogenous factors (X)** are outside of the control of the water managers and are often uncertain or not completely understood (e.g., climate change and demographic growth).

- **Policy levers (L)** are actions taken by water managers to alter the outcomes (maintaining current operations are considered to be the first in very long list of potential actions).

- **Relationships (R)** describe how the factors interact with one another and govern the final output. The relationships in this case are represented by climate models, rainfall runoff models, water resource systems models and in some cases water quality models.

- **Performance measures (M)** are metrics that water managers use to determine the success of various strategies under different scenarios.

© ASCE 2014

Risks are managed through available levers (**L**) to ensure successful outcomes as measured by performance metrics (**M**), subject to a wide range of uncertain future conditions (**X**). Decision science (or risk management) offers a number of approaches when considering the uncertainty inherent in climate change adaptation analysis.

2.3 WEAP Model

The WEAP model is ideally suited to explore water supply/demand in support of integrated water resource management planning (IWRP) objectives. WEAP has been used worldwide, as a tool to explore municipal water supply options and in support of IWRP processes. Its graphical, intuitive nature supports rapid model building of real water resource systems while its strong link to climate via watershed hydrology helps a water service provider explore the implications of climate change on its water system (including the tradeoffs between competing water uses). The tradeoffs between water for irrigation, municipal water supply, hydropower generation, environmental flows, etc. can be rapidly and meaningfully explored with WEAP.

In the partnership, NCAR and Palm Beach worked with MWSS, Manila Water and Maynilad Water to use WEAP to develop and assess scenarios that explored physical changes to their water system, such as new reservoirs or pipelines, as well as social changes, such as policies affecting population growth or the patterns of water use. The partnership also enabled better linkages between the water services providers and relevant organizations such as PAGASA and the National Electric Commission on data sharing

2.4 Summary of the WEAP Model for Manila Water and Maynilad Water

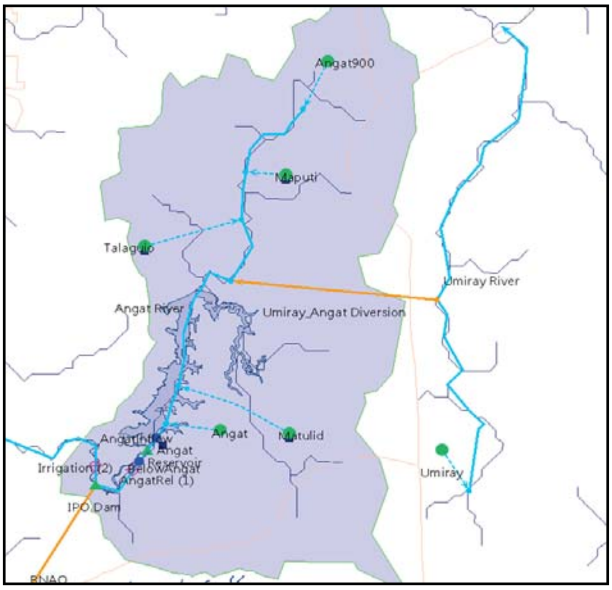


Figure 2. The Angat Watershed in WEAP-Manila. The Green dots are catchment objects

The WEAP model built for this project is referred to as WEAP-*Manila*, with a focus on the Angat Watershed (Figure 2) as the primary water supply for the two water concessionaires – Manila Water and Maynilad Water – and MWSS.

The Manila Water and Maynilad water supply is derived mainly from the Angat Watershed. The Angat Reservoir is managed by the

© ASCE 2014

National Power Corporation, and a primary and competing purpose of the reservoir is hydropower production. Releases are made from Angat to generate power, to deliver water to Ipo dam for diversion to the Manila Water and MayniladWater supply system primarily through La Mesa Reservoir. Below Ipo dam, water is needed for irrigated agriculture.

2.4.1. Future Climate Projections

There are several ways of generating future climate scenarios for impact and adaptation analysis. Some approaches rely heavily on the results from Global Climate Models (GCMs), while others do not have this dependency and make use of purely statistical methods based on prior observations and assumptions about future climate. GCMs are used to simulate past, present, and future global climate conditions, including impacts from greenhouse gas emissions and their subsequent forcing of the climate system. Many research centers around the world that have developed GCMs, make their model results available to the climate change impacts community, and while the projections of temperature change are often in general agreement, there is much less agreement about future changes in precipitation. Thus, selecting a single GCM projection for use in impact and adaptation assessments cannot adequately represent the inherent uncertainty in projections of future climate as represented by modern GCMs.

Current generation climate models are generally able reproduce the warming that occurred over the 20th century when run in a "'hindcast'" mode using estimates of historical greenhouse gas concentrations. These models are also able to reproduce some of the key climate characteristics of paleoclimates that were far different than today's climate, which lends additional confidence that GCMs' future simulations will be generally realistic. Problematic to water planners, however, outputs from GCMs are typically available at spatial scales of 100 kilometers or more. Furthermore, different GCMs run under the same greenhouse gas emissions forcing scenario can produce profoundly different projections of temperature and precipitation change, particularly at the regional scale.

This analysis is performed at a regional scale, area-averaging data from a minimum of four grid points into regional means of temperature and precipitation change. For any given season and greenhouse gas emissions scenario, the Bayesian model is able to derive a probability density function of temperature and precipitation change. The available emissions scenarios are SRES scenarios A2 (high), A1B (midrange), and B1 (low emissions); and change is the difference between two 20-year averages, for example 1980-1999 (the typical "current climate" period) versus 2080-2099.

© ASCE 2014

Table 2. Change in Temperature and Precipitation for the A2 Scenario, derived from the distributions shown above

A2	Precipitation	Temp (°C)
Jan-Mar	-5.9%	1.7
Apr-Jun	-6%	1.6
Jul-Sep	-5%	1.7
Oct-Dec	-5.2%	1.8

2.4.2 Climate Change Results

Projected demands and the supply delivered to meet those demands are shown in 3, suggesting modest growth out to 2050. This single demand projection is meant to demonstrate the kinds of exogenous factors (X's) that can be explored in the WEAP-*Manila* model.

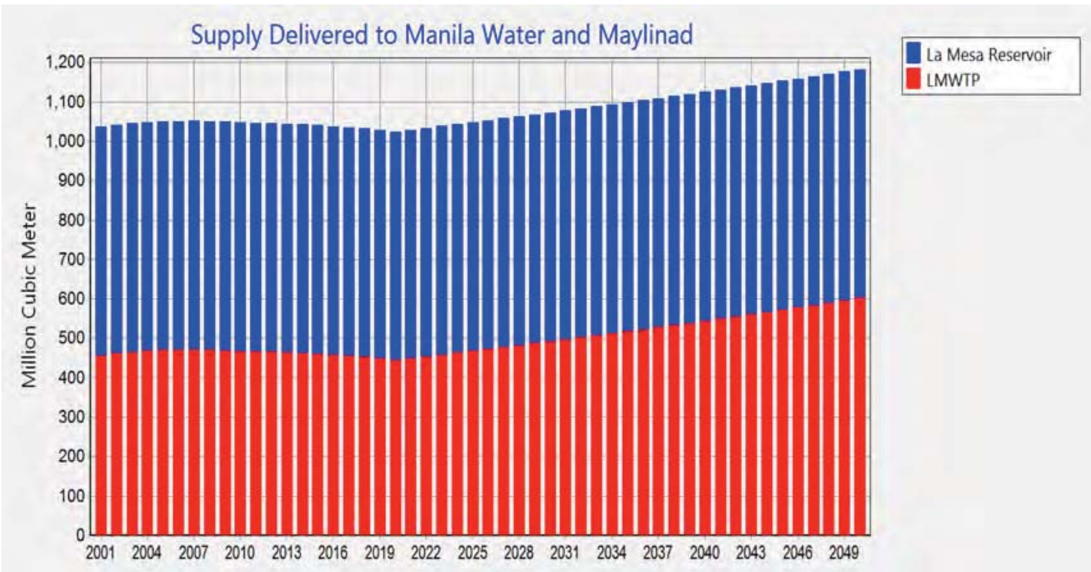


Figure 3. Projected Supply Delivered to the Manila Water and Maynilad Concessionaires Out to 2050 *Note: the growth is from assumptions about population growth, with per-capita demand held constant*.

As discussed, the projected changes in future precipitation and temperature relative to the already substantial rainfall amounts, warm temperatures, and high humidity over the watershed, were relatively modest. This was particularly true for the higher elevations of the Angat Watershed, where daily mean rainfall amounts were likely well above 35mm/day.

© ASCE 2014

The GCM-based, projected changes on the order of 1 mm/day in rainfall and increase of 1.5°C within a humid, sub-tropical environment means that changes in runoff and subsequent changes in reservoir storage were relatively modest (Figure 4). The projected decrease in hydropower generation from Angat reservoir for this drier and warmer scenario was on the order of 7%.

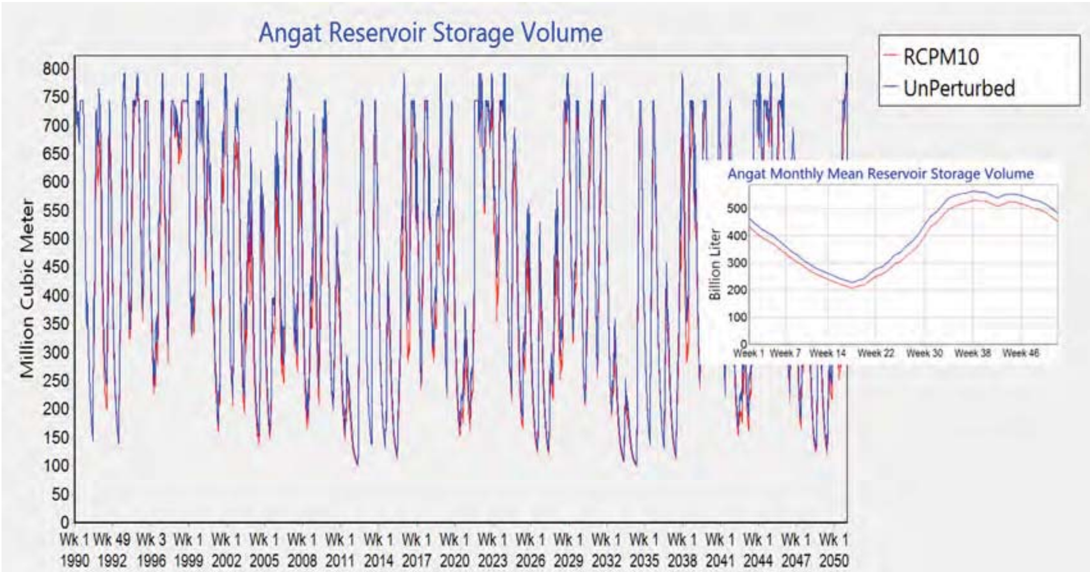


Figure 4. Projected Storage in Angat Reservoir Assuming that: (1) the historic climate repeats itself (Unperturbed) and (2) the A2 scenario at the 10th percentile change level with a decrease in seasonal precipitation and about a 1.5°Cannual increase in temperature. *Note: the inset graph is the monthly mean of the time series.*

These outcomes were likely conservative, as the partners did not explore the inter-annual variability that is suggested by any of the climate models that were represented in the inter-model comparison conducted by Tebaldi et al., 2005. The partners simply imposed a change signal onto the observed climate, and assumed that this perturbed climate repeated itself into the future. *Note: Future studies should explore the inter-annual variability suggested by various climate models and the use of regional climate models to explore the possible changes in the higher elevations of the Angat Watershed.*

© ASCE 2014

3. LESSON AND CHALLENGES

During the partnership, technical staff from MWSS, Manila Water and Maynilad Water attended hands-on and classroom training by NCAR and Palm Beach on using and applying WEAP. While NCAR gave overall technical support for WEAP usage, Palm Beach imparted its practical experiences to its Manila peers.
Key challenges encountered by MWSS, Manila Water and Maynilad Water in the WEAP application process included:

1. ***Lack of sufficient (hydrological/climate) data***. Data remain vital in narrating past incidences. The Manila-based service providers derived projections based on historical patterns; designed structures based on historical events and developed contingencies based on historical extremes. The partnership and the WEAP application process enabled MWSS, Manila Water and Maynilad Water to further recognize the importance of collecting climate-related data. These data were gathered from four rain gauging stations located alongthe Angat Watershed: (1) Matulid, (2) Talaguio, (3) Maputi and (4) Angat. These stations have the capacity to measure only precipitation, which translates to the amount of rainfall delivered to the Angat Reservoir. Other key figures for the WEAP (e.g., humidity, temperature and wind velocity) were obtained from Science Garden Laboratory in Quezon City and another laboratory in Infanta, Quezon, both operated by PAGASA.

2. ***Lack of access to data/quality data***. MWSS, Manila Water and Maynilad Water visited various agencies to collect data as needed and specified by NCAR for the WEAP simulations. However, accessing the data required a formal process including several letters, agreements and discussions on data usage and types of data needed. Relevant agencies are mandated to safeguard data and thus had instituted controls on access, resulting in the delay to get data necessary for the partnership activities. They tend to protect the data that they generate for institutional or educational purposes only and have no mechanisms in place to share with other departments or agencies for common usage. Until an accurate depiction of the spatial and temporal characteristics of rainfall are made over the Angat Watershed, it will be difficult to accurately simulate hydrologic processes.

3. ***Lack of understanding of climate change***. Technical understanding and familiarity with climate change-related terms or subjects were limited and thus the WEAP application runs had start-up delays. For instance, involved representatives from MWSS, Manila Water and Maynilad Water were not familiar with different climate projections such as the A1b or A2 scenarios, which would facilitate the WEAP simulations.

© ASCE 2014

They were also not exposed to concepts of climate science such as climate forcings and climate variability that would have improved their integration of climate factors into the WEAP runs.

4. ***Limited regional climate change projections***. The future climate scenarios used in this activity were derived from a consensus of climate models using Bayesian statistical techniques summarized in Tebaaldi et al., 2005. These projections showed changes in the seasonal mean only, and did not give any indication of how the inter-annual variability of climate might change. Some scenarios suggested overall warming and drying over the basin, but these projected changes were relatively modest when compared to the contemporary climate. Precipitation change was on the order of a 1 mm/day and 1.5°C by 2050 for the A2 IPCC 4th Assessment Report projection. Future studies should include the use of higher resolution, regional climate modeling experiments and inter-annual variability to explore a wider range of vulnerabilities to the Manila water supply.

4. RECOMMENDATIONS

The partnership verified the importance of the collaboration between the various water agencies, research organizations, the water concessionaires, and their regulator. The general topic of "Climate Change" served as a catalyst to bring the various organizations together to explore new water management tools, decision frameworks such as XLRM, discussion and training on climate change projections, etc. Several lessons and recommendations below were provided by staff from MWSS, Manila Water and Maynilad who were involved in associated training in climate change and on the use of the WEAP model and the development of the WEAP-*Manila* application:

1. ***Involving related agencies in the process***. The WEAP software has many capabilities and would benefit many other agencies provided that the users recognize its limitations and the desired outputs. These agencies include the National Water Resources Board (NWRB), PAGASA, National Irrigation Administration (NIA), and National Power Corporation. Each agency is a stakeholder in the use of water from the Angat Watershed. NWRB is particularly important since it regulates water allocation for Angat's stakeholders (NIA, NPC and MWSS). Its role is especially critical for planning water allocation during El-Niño or La-Niña events. Involving these agencies in the WEAP development model and XLRM framework application would enhance the outcomes of the WEAP application.

© ASCE 2014

2. ***Applying innovative technology for monitoring.*** The Manila partners noted the availability of innovative instruments that can monitor weather conditions and have the capability to send gathered information directly to a user's computer for real time monitoring.

   The installation of such monitoring stations within watersheds of the different water sources for Manila (i.e., Angat, Ipo and LaMesa) and adjusting their capabilities to monitor climatic conditions as well as create scenarios (assuming dams are built within those areas) would maximize the WEAP's capacity in producing models that will benefit future planning and decision making options.

3. ***Establishing a technical working group***. Since climate change is a key concern for water services providers in the Philippines, the establishment of a technical working group (TWG) on modeling/planning using tools such as WEAP would confirm management interest to integrate climate factors into current planning processes. The TWG could focus on modeling (e.g, using WEAP) and analyzing model outcomes for planning and decision-making. It could report the tool application and results during local and national level events on building climate resilience and support further application of the tools by other interested agencies.

4. ***Researching demand-sidestorm water and wastewater systems.*** The partnership activities focused on the supply side of the Manila water supply system. Projected changes in precipitation and temperature over the Angat Watershed were relatively modest, and changing the management and operation of Angat Reservoir were outside the operational jurisdiction of the concessionaires. As such and in the context of the XLRM analysis that was introduced, there were insufficient (L)evers for either Manila Water or Maynilad to explore.

© ASCE 2014

REFERENCES

Giles, J. (2002). "When Doubt is a Sure Thing." Nature, 418, 476-478.

Lempert, R. J., Popper, S. W., and Bankes, S. C. (2003). Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis, RAND, Santa Monica, CA.

Miller, K., and D. Yates.(2006) Climate Change and Water Resources: A Primer for Municipal Water Providers, Awwa Research Foundation and UCAR, IWA Publishing, Denver, CO, 83 pp.

O'Neil, K. and D. Yates. (2011). A Dynamic Decision Support System: Linking Water Resource Simulation and Decision Analysis, Water Research Foundation, #4074, Denver CO.

Reilly, J., Stone, P. H., Forest, C. E., Webster, M. D., Jacoby, H. D., and Prinn, R. G. (2001). "Uncertainty and Climate Change Assessments." Science, 293, 430-433.

Schneider, S. H. (2001). "What is 'Dangerous' Climate Change?" Nature, 411, 17-19.

Tebaldi, C., R. L. Smith, D. Nychka, and L. O. Mearns. (2005)."Quantifying Uncertainty in Projections of Regional Climate Change: A Bayesian Approach to the Analysis of Multimodel Ensembles," Journal of Climate, 18(10), 1524–1540.

Yates, D., J. Sieber, D. Purkey, and A. Huber-Lee.(2005)."WEAP21 – ADemand, Priority, and Preference-Driven Water Planning Model: Part 1 – Model Characteristics," Water International, 30(4), 487-500.

Evaluation of PAH and Metal Contents of Different Biochars for Use in Climate Change Mitigation Systems

Erin N. Yargicoglu[1] and Krishna R. Reddy[2]

[1]Graduate Research Assistant, University of Illinois at Chicago, Department of Civil and Materials Engineering, 842 West Taylor Street, Chicago, Illinois 60607, USA; eyargi2@uic.edu
[2]Professor, University of Illinois at Chicago, Department of Civil and Materials Engineering, 842 West Taylor Street, Chicago, Illinois 60607, USA; kreddy@uic.edu

ABSTRACT

Biochar, a solid byproduct generated during biomass pyrolysis or gasification in the absence (or near-absence) of oxygen, has recently garnered interest for both agricultural and environmental uses owing to its unique physical and chemical properties, such as its high surface area and porosity, and ability to adsorb a variety of compounds, including nutrients, organic contaminants, and some gases. This material is also considered 'sustainable' as it can be derived from agricultural wastes and is currently being investigated for carbon sequestration applications and as a soil cover amendment for reduced greenhouse gas emissions from landfills. Ongoing research in our laboratory has shown that biochar can enhance both methane adsorption and subsequent microbial oxidation in soils, making it a promising material to mitigate residual landfill emissions for which gas recovery is not economical or feasible. Physical and chemical properties of biochar are dictated by the feedstock and production conditions (i.e. temperature, conversion technology and post-treatment processes, if any), which vary widely across commercially produced biochars. In this study, several commercially available biochars are characterized for key physical and chemical properties relevant to the common uses of biochars in environmental applications, with special attention given to PAH and heavy metal content and leachability. A high variability in chemical composition, surface properties, and PAH and heavy metal contents among commercially available biochars was observed, underscoring the importance of pre-screening biochars for the presence of PAHs and heavy metals prior to selection as a landfill cover or soil amendment.

INTRODUCTION

The push for sustainability in both commercial and domestic activities has spurred interest in the use of waste products from a variety of processes for secondary uses, including climate change mitigation applications such as engineered landfill covers. As a result, biochar – a solid byproduct obtained from the pyrolysis or

© ASCE 2014

gasification of biomass in a low or zero oxygen environment - has recently gained popularity as an agricultural amendment and for environmental remediation and carbon sequestration (Kookana et al., 2011; Spokas et al., 2012; Xie et al. 2014). Biochar, syngas, and synfuel are produced during combustion of organic residues, such as during waste incineration or biofuel production. While agricultural applications are the earliest recorded uses of this material (Glaser et al. 2001), recent and ongoing research indicates that biochar has potential to be an effective adsorbent for landfill gases such as CH_4 (Yaghoubi, 2011; Reddy et al. 2014a) as well as for some organic and inorganic contaminants (Reddy et al. 2014b). The safe use of biochar in any of these applications must understandably be evaluated before wide-scale implementation can move forward.

Because biochar is produced during incomplete combustion of organics, there is a potential to form polycyclic aromatic hydrocarbons (PAHs) during its production, which may then remain sorbed to the hydrophobic surface of biochar (Jonker and Koelmans, 2002). Sorption of organic molecules to biochar results from strong π-π interactions that occur between the planar aromatic sheets of biochar and the PAH molecule (Hale et al., 2012). Due to this strong sorption, the bioavailability of PAHs is thought to be relatively low, though it is unclear whether these sorbed toxins desorb slowly into the environment over long timescales (Hale et al., 2012; Keiluweit et al., 2012). The amount of PAHs produced during pyrolysis is related to the production conditions and method of heat treatment, and is thus expected to vary among commercial producers using different process technologies and controls (Hale et al. 2012). Several PAHs are known carcinogens and/or mutagens; thus their occurrence in biochars must be evaluated prior to their safe application to the soil for agricultural or other environmental remediation purposes. The toxicity of heavy metals that can be found in charred material, such as As, Cu, Cd, Pb, Mn and Zn, is also well documented and should be considered.

To date, only a limited number of studies have specifically investigated PAH and heavy metals contents of biochars (Hilber et al., 2012; Hale et al., 2012; Keiluweit et al., 2012; Kloss et al., 2012), with the primary emphasis on the total PAH content rather than the leachability of these toxic constituents. However, compared to total PAH content, leachability is more relevant in assessing human and ecological health risks associated with biochar application to soils, as the leachable fraction represents the amount that poses a risk to human receptors. Among recent studies evaluating biochars for their toxin content, bioavailability of toxic compounds to plants and soil microbiota in biochars was specifically assessed by Hale et al. (2012) and Oleszczuk et al. (2013). Kloss et al. (2012) similarly addressed ecotoxicity of PAHs and heavy metals in slow pyrolysis biochars using a suite of biological toxicity assays.

The purpose of this study is to evaluate the total PAHs and metals in solid biochars from commercial producers as well as their leachable fractions. Six commercially available waste wood-derived biochars were selected and tested for their physical and chemical properties and total and leachable PAH and metals content. The contaminant concentrations of each biochar are then compared with the typical thresholds for harmful effects. Finally, various factors that affect the presence of contaminants in biochar are presented and discussed.

© ASCE 2014

METHODOLOGY

Six biochars were obtained from four different commercial producers. In addition to these biochars, granular activated carbon (GAC) obtained from Fisher Scientific was also tested. Table 1 summarizes the feedstock and processing conditions for the selected biochars. These biochars were characterized for various physical and chemical properties and also tested for the concentrations of 16 priority pollutant PAHs and 22 heavy metals in the solid biochar matrix. PAHs were extracted from the biochars using ultrasonic extraction and subsequently quantified via gas chromatography-mass spectrometry (GC/MS) according to USEPA Method SW8270C. Metal contents of the solid biochars were determined following acid digestion of the solid samples; analyses were then performed using inductively coupled plasma mass spectrometry (ICP/MS) according to EPA Method SW6020 for all metals except for mercury and cyanide, which were analyzed according to USEPA Methods SW 7471A and SW9012A, respectively.

Table 1. Production conditions and source materials of biochars used in this study (BDL: below detection limit; NR: not reported).

Biochar ID	Feedstock	Treatment Process	Temp.	Residence Time	Post-Treatment	H:C Ratio
BS	Pine wood	Slow pyrolysis	350 – 600°C	6 hrs	Screened through 3mm mesh	0.35
CK	90% pine & 10% fir wood	Fast pyrolysis	> 500°C	< 1 hr	Activated with O_2	0.18
AW	Aged oak & hickory wood biochar	Pyrolysis – Missouri type concrete kiln	~500°C	NR	Mixed with proprietary innocula blend & sieved (1/4”)	0.51
CE-AWP	Pinewood pellets	Gasifi-cation	~520°C	NR	-None (aged for >1 year)	0.27
CE-WP1					-Fine ash retained	0.63
CE-WP2					-Fine ash sieved	0.61

The biochars were then subjected to hydraulic conductivity testing using the constant-head method as specified in ASTM D2434. Briefly, samples of biochars were placed into the permeameter cells and saturated with deionized water. The first pore volume of water leaching through the sample was collected and retained for analysis of metals and PAHs. For biochars in which PAHs were detected in the solid samples (i.e. AW, BS, and CK biochars), the leachate was subsequently analyzed for the same suite of PAHs and heavy metals to determine the concentrations in the leachate (i.e. the water-soluble constituents). PAHs were extracted from liquid

© ASCE 2014

samples using liquid-liquid extraction with methylene chloride as the solvent and quantified via GC/MS. H:C molar ratios of solid biochars were determined by elemental analysis using a PerkinElmer 2400 Series II CHNS/O Elemental Analyzer operated in CHN mode.

RESULTS & DISCUSSION

Polycyclic Aromatic Hydrocarbons (PAHs) in Biochars

PAHs were not detected in GAC. Of the six biochars tested, only three had detectable PAHs in the solid biochars: AW, BS, and CK biochars, made from traditional pyrolysis in a concrete kiln ('Missouri type' as stated by the producer), and slow and fast pyrolysis, respectively. Figure 1 shows the detected PAHs and their concentrations. All three were derived from wood, though the type and age of wood used varied as indicated in Table 1. CK biochar (fast pyrolysis) had the highest PAH content (~ 83 mg kg^{-1}). This biochar was a very fine powder, with much smaller particle size than the pelleted CE biochars; consequently, sorption of PAHs to this biochar may be higher due to the greater surface area available for sorption, potentially resulting in the elevated PAH content observed.

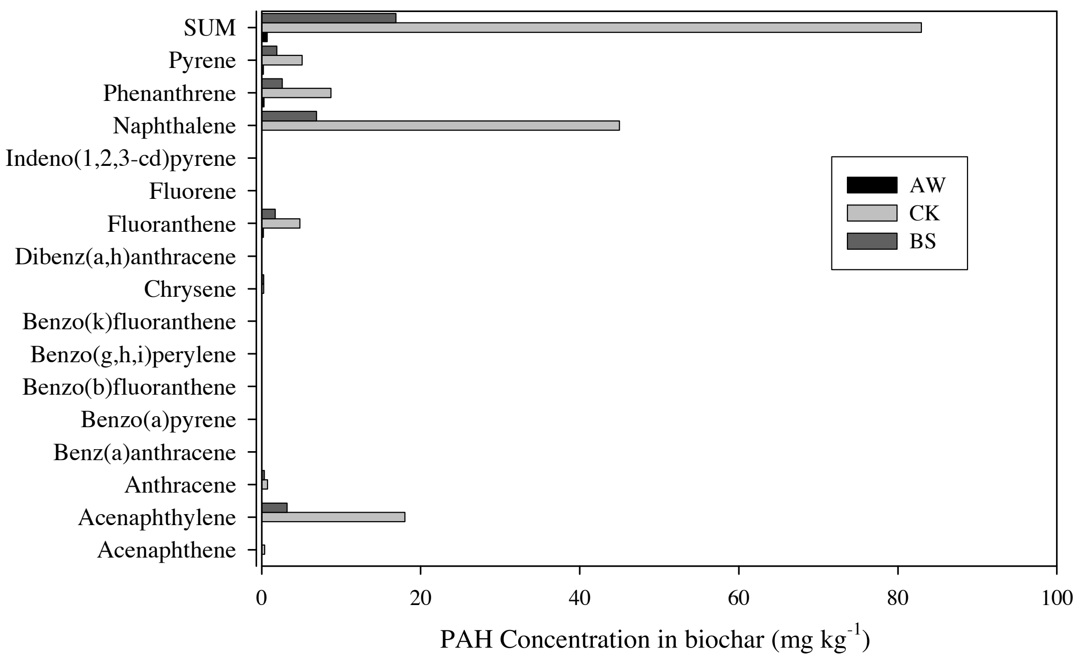


Figure 1. PAH concentrations detected in biochars in this study in mg kg^{-1} (PAHs were not detected in the other three biochars tested).

© ASCE 2014

Table 2. PAH concentrations determined for biochars in this study as well as four 'representative' biochars tested in the method optimization study by Hilber et al. (2012). All concentrations given in mg kg^{-1}.

PAH	This Study			Hilber et al. (2012)			
	AW	CK	BS	Grapevine wood biochar, 1 yr old	Miscan -thus biochar	Coniferou s wood residues	Mixed wood residues
Acenaphthene	0.00	0.38	0.00	0.109	0.498	1.699	0.189
Acenaphthylene	0.00	18	3.2	0.038	5.495	38.73	0.367
Anthracene	0.00	0.74	0.32	0.419	1.772	9.774	0.33
Benz(a)anthracene	0.00	0.00	0.00	0.14	0.94	4.42	0.13
Benzo(a)pyrene	0.00	0.00	0.00	0.06	1.43	4.71	0.06
Benzo(b)fluoranthene	0.00	0.00	0.00	0.02	0.86	3.60	0.08
Benzo(g,h,i)perylene	0.00	0.00	0.00	0.02	1.13	2.82	0.04
Benzo(k)fluoranthene	0.00	0.00	0.00	0.04	0.46	2.11	0.05
Chrysene	0.00	0.25	0.27	0.15	1.06	4.81	0.17
Dibenz(a,h)anthracene	0.00	0.00	0.00	0.00	0.05	0.24	0.00
Fluoranthene	0.2	4.8	1.7	0.22	6.63	31.527	0.43
Fluorene	0.00	0.00	0.00	0.61	0.26	0.99	0.09
Indeno(1,2,3-cd)pyrene	0.00	0.00	0.00	0.04	0.69	3.15	0.04
Naphthalene	0.00	45	6.9	5.94	26.09	181.16	5.14
Phenanthrene	0.28	8.7	2.6	1.76	9.51	48.84	1.61
Pyrene	0.2	5.1	1.9	0.25	5.87	22.46	0.36
Total PAH	0.68	83.0	16.9	9.82	62.73	361.03	9.09

Naphthalene, a low-weight and highly volatile PAH, constituted the majority (~54%) of detected PAHs in the CK biochar with a concentration of 45 mg kg^{-1} in the solid char. This trend is consistent with previous studies, who also observed a dominance of naphthalene in wood-derived chars, especially at shorter pyrolysis times (Kloss et al., 2012; Hale et al., 2012). Kloss et al. (2012) observed drastic increases in naphthalene concentrations relative to other PAHs with an increase in temperature from 400 to 525°C in straw, spruce and poplar derived biochars. This indicates increasing volatility of the generated PAHs with higher temperatures, which is also correlated with decreasing toxicity, as the semivolatile, higher-weight PAHs (e.g. benzo(a)pyrene) are generally more toxic (Kloss et al. 2012).

The absence of detectable PAHs in biochars produced via gasification (i.e. CE biochars) may be due to the presence of oxygen in the reaction chamber, which would lead to more complete combustion of organic matter and reduce PAH formation due to incomplete combustion. This is contrary to the trend observed by Hale et al. (2012), who found the highest PAH content in biochar produced via gasification (45 µg g^{-1}). Differences in production conditions among vendors may be responsible for these discrepancies as seen Table 2. One other possible explanation for the large variation in PAH contents observed by previous studies may be related

© ASCE 2014

to the method of PAH extraction used. Hilber et al. (2012) investigated this issue further in a method optimization study that compared PAH recovery efficiencies using various chemical extraction procedures. Hilber et al. found that conventional extraction techniques for soils were often insufficient for extracting PAHs from biochar due to strong sorption of PAHs onto surface of biochar. They recommend a 36 hour Soxhlet extraction with 100% toluene for optimal extraction efficiency.

Heavy Metals in Biochars

Figure 2 and Figure 3 show the concentrations of nontoxic metals and toxic metals, respectively, in the tested GAC and biochars. Other than an overall enrichment in metal content typically observed as biomass is pyrolyzed further, prior studies have not confirmed any strong correlations with process conditions and heavy metal content of biochars; rather, metal content appears to reflect that of the source materials, though typically higher concentrations due to loss of carbon and organic matter during pyrolysis. Overall, in this study, heavy metal contents of the biochars were fairly low, though higher than in GAC, as seen in Figures 2 and 3, showing similar trends as with PAH content.

The highest concentrations of most metals in the solid samples were typically found in CK biochar (ΣMetals = 148.9 g kg^{-1}), followed by BS and AW biochars (ΣMetals = 50 and 41.4 g kg^{-1}, respectively). This is attributed to an increasing degree of carbonization of the chars (as indicated by decreasing H:C ratios; refer to Table 1) leading to an enrichment of the heavy metals present in the raw source material. Distinct effects of source materials on water-extractable trace elements were also noted by Kloss et al. (2012), Olezczuk et al. (2013), and Lucchini et al. (2013) in their investigations. Consequently, biochars derived from treated (waste) wood should be used with caution, as they tend to have higher toxin contents, especially heavy metals, as shown by Lucchini et al. (2013). Though overall metal concentrations in these biochars were low, some metals were more prevalent in the solid biochar than others, e.g. Zn, Mn, Pb, especially in the CK biochar.

Leachable Constituents of Biochars Studied

Metal concentrations in the leachate of biochars with detectable PAHs in the solid form are shown in Table 3. All tested PAHs were below detection limits in all leachate samples; heavy metals were also relatively low, with only two cases in which metal concentrations exceeded Tier I groundwater remediation standards (Table 3) for potable water sources in the state of Illinois (Pb and Mn in CK leachate). Even in these cases, the exceedance is relatively minor and concentrations are low enough to satisfy water quality standards for industrial/commercial uses (i.e. Class II groundwater standards, see Table 3). However the long-term stability of these sorbed constituents must be evaluated more thoroughly in order to determine the long-term health risks associated with biochar application to soils (Keiluweit et al., 2012).

© ASCE 2014

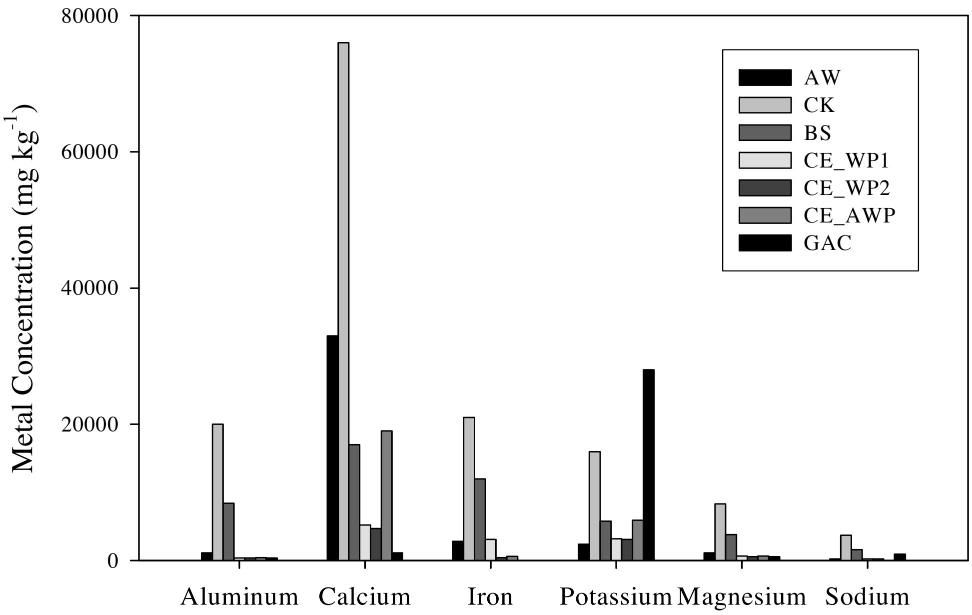


Figure 2. Nontoxic metal concentrations in biochars and granular activated carbon.

Table 3. Metals above the detection limit in tested biochar leachate. All other metals (Sb, As, Be, Cd, Cr, Co, Hg, Ni, Se, Ag, Th, V, Zn) were below the detection limits.

Metal	Units	Class I GW	Class II GW	AW	BS	CK
Aluminum	mg/L	---	---	1.5	0.62	< 0.4
Barium	mg/L	2.0	2.0	0.12	0.065	0.064
Calcium	mg/L	---	---	54	16	25
Copper	mg/L	0.65	0.65	< 0.1	< 0.1	0.12
Iron	mg/L	5.0	5.0	1.7	< 1	< 1
Lead	mg/L	0.0075	0.1	0.038	< 0.02	< 0.02
Magnesium	mg/L	---	---	7.3	11	5.9
Manganese	mg/L	0.15	10.0	0.28	0.077	< 0.04
Potassium	mg/L	---	---	72	94	260
Sodium	mg/L	---	---	5.6	11	53

© ASCE 2014

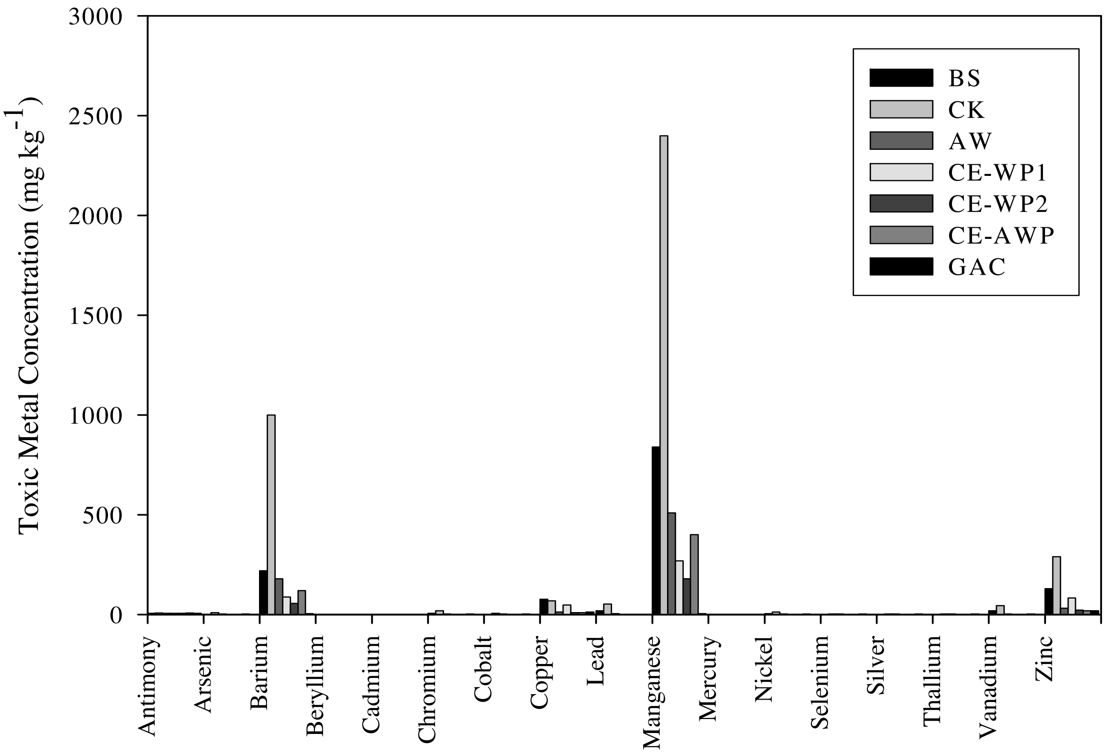


Figure 3. Toxic metal concentrations in biochar and granular activated carbon.

This study results indicating low leachability of sorbed PAHs are consistent with findings from prior research studies. Hale et al. (2012) found that, in general, bioavailability of PAHs in biochar was fairly low, likely due to strong sorption to the surface of the biochar or the occurrence of PAHs in occluded pores, which are not exposed to the outer surface and thus not accessible by plants or microorganisms (Cornelissen et al., 2005; Hale et al., 2012; Keiluweit et al., 2012). Highest bioavailable PAH concentrations were generally associated with shorter pyrolysis times or gasification (Hale et al., 2012). Other key factors that may affect the extent of PAH sorption on biochars include the use of post-processing treatments, storage conditions, and the extent of biochar ageing, and the effects of these factors on PAH leachability (or availability) requires additional research.

Role of Production Conditions on Toxin Content

Several researchers have concluded that slow pyrolysis times, high treatment temperatures (i.e. 400-600°C), and woody source materials lead to the lowest PAH contents in biochars (Hale et al., 2012; Keiluweit et al., 2012; Kloss et al., 2012; Oleszczuk et al., 2013). Though it is difficult to discern differences due to feedstock

© ASCE 2014

from this study (all biochars were wood-based), clear differences due to production processes are observed. All three of the biochars produced via gasification had PAH concentrations below the detection limit for all 16 PAHs tested. This result differs from the findings of Hale et al (2012), in which the highest PAH content was found in a gasification-produced biochar. They speculated that gasification may actually lead to higher PAH contents due to a higher rate of PAH forming reactions taking place (Hale et al., 2012). However, it is possible that the incorporation of a greater amount of O_2 during gasification lead to more complete organic matter combustion to CO_2, thereby reducing the formation of volatile aromatic hydrocarbons, such as PAHs (Spokas et al., 2011). It is important to note that previous investigations by Spokas et al. (2011) on sorbed volatile organic compounds on biochar have found high variability in the amount and composition of aromatic products generated, with no consistent relationship of chemical characteristics with temperature or pyrolysis conditions observed, especially among the slow pyrolysis biochars.

Though Spokas et al. (2012) did not include all PAHs in their study (i.e. only low-weight, volatile PAHs were included, such as naphthalene were included), it is thought that similar processes are responsible for the formation of semi-volatile species during combustion, namely through the accumulation of single aromatic rings to form polycyclic species. It was also found that post-production treatment processes (e.g. activation, storage and handling) can have a significant impact on the quantity of sorbed volatile species (Spokas et al., 2011); the extent to which this impacts semi-volatile species requires further research. CK biochar was the only biochar included in this study that was subjected to activation with O_2 following pyrolysis, which may have led to increased sorption of PAHs to its surface due to a greater functional surface area. The implications of post-treatment processes on PAH sorption should be further investigated to better understand the mechanisms of PAH sorption to biochars and to determine whether these sorbed species can be readily mobilized into solution.

Earlier research has noted that fast pyrolysis may lead to higher PAH concentrations due to the condensation of generated PAHs on the biochar surface during production, rather than be burned off later as during slow pyrolysis (Hale et al., 2012). In general, Hale et al. observed highly variable PAH contents among the different chars, with generally lower total PAH concentrations in biochars produced via slow pyrolysis relative to that produced via fast pyrolysis or gasification. PAH generation appeared to be highest for slow pyrolysis biochars at treatment temperatures in the 350 to 550 °C range (Hale et al., 2012). Similar results were found by Keiluweit et al. (2012), who also observed the highest PAH concentrations in biochars produced at temperatures between 400 and 500°C. These findings are somewhat supported by the results of this study, as the fast-pyrolysis biochar (CK) had significantly greater total PAHs than any of the other studied biochars produced via slow pyrolysis or gasification. This is also a promising finding for the development of production guidelines for minimal toxin content in commercial biochars, as the heating times and/or temperatures can simply be increased to burn off PAHs that may be generated and subsequently sorbed to the biochar. Further testing will be needed to determine the minimum residence times and temperatures necessary to eliminate sorbed PAHs from the variety of source materials commonly used to produce biochar.

© ASCE 2014

Given the significant variability among biochar properties and the fact that PAHs are inherently produced during biochar production, concerns remain regarding the safe use of biochars, especially in agricultural applications. The USEPA has set a limit of 6 mg kg^{-1} of total PAH concentrations in biosolids applied to land (NRC, 2002); though no analogous standard exists for biochar, one may adopt this standard for biochar amendments to soil. Following this standard would result in the prohibition of many biochars from land application, even if the bioavailable PAH concentrations are relatively low. A better understanding of PAH mobility from biochars is needed in order to inform its safe use in environmental and agricultural applications. Prior studies that had concluded biochars had negligible PAH contents only evaluated laboratory-produced biochars (e.g. Singh et al., 2010), which can differ widely from the chars available commercially. This study demonstrates the importance of pre-screening biochars for toxic constituents prior to application in the field in order to minimize potential worker exposure or environmental contamination.

CONCLUSIONS

This study quantified the concentrations of sixteen priority pollutant polycyclic aromatic hydrocarbons and 22 metals in six commercially-available biochars as well as in granular activated carbon. Only half of the tested biochars had detectable PAHs in the solid phase, and given the very low concentrations in the leachate, are apparently not readily mobilized in solution. It appears that these biochars are safe for use in soils given the relatively low concentrations of contaminants in the leachate. However, in terms of total PAH content, two of the six tested biochars did exceed standards for biosolids applied to land in the US of 6 mg kg^{-1} total PAH content. Thus, it is imperative to pre-screen biochars obtained from different vendors and source materials in order to ensure their safe use. Additional process control measures should also be taken to minimize PAH production, e.g. by increasing pyrolysis residence time or heat treatment temperature to burn off volatile compounds after they are generated. Further research is needed in order to better understand the mechanisms responsible for PAH and metal contents in biochars so that guidelines to minimize their production or enrichment during biochar manufacturing can be established.

ACKNOWLEDGMENTS

The authors of this study would like to gratefully acknowledge the National Science Foundation (Grant CMMI #1200799) for providing financial support for this research.

REFERENCES

Cornelissen, G., Gustafsson, Ö., Bucheli, T. D., Jonker, M. T. O., Koelmans, A. A., and van Noort, P. C. M. (2005). "Extensive sorption of organic compounds to black carbon, coal, and kerogen in sediments and soils: Mechanisms and

© ASCE 2014

consequences for distribution, bioaccumulation, and biodegradation." *Environ Sci Technol*, 39(18), 6881-6895.

Glaser, B., Haumaier, L., Guggenberger, G., and Zech, W. (2001). "The 'Terra Preta' phenomenon: a model for sustainable agriculture in the humid tropics." *Naturwissenschaften*, 88(1), 37-41.

Hale, S. E., Lehmann, J., Rutherford, D., Zimmerman, A. R., Bachmann, R. T., Shitumbanuma, V., O'Toole, A., Sundqvist, K. L., Arp, H. P. H., and Cornelissen, G. (2012). "Quantifying the total and bioavailable polycyclic aromatic hydrocarbons and dioxins in biochars." *Environ Sci Technol*, 46(5), 2830-2838.

Hilber, I., Blum, F., Leifeld, J., Schmidt, H.-P., and Bucheli, T. D. (2012). "Quantitative determination of PAHs in biochar: A prerequisite to ensure its quality and safe application." *J Agr Food Chem*, 60(12), 3042-3050.

Jonker, M. T. O., and Koelmans, A. A. (2002). "Sorption of polycyclic aromatic hydrocarbons and polychlorinated biphenyls to soot and soot-like materials in the aqueous environment: Mechanistic considerations." *Environ Sci Technol*, 36(17), 3725-3734.

Keiluweit, M., Kleber, M., Sparrow, M. A., Simoneit, B. R. T., and Prahl, F. G. (2012). "Solvent-extractable polycyclic aromatic hydrocarbons in biochar: Influence of pyrolysis temperature and feedstock." *Environ Sci Technol*, 46(17), 9333-9341.

Kloss, S., Zehetner, F., Dellantonio, A., Hamid, R., Ottner, F., Liedtke, V., Schwanninger, M., Gerzabek, M. H., and Soja, G. (2012). "Characterization of slow pyrolysis biochars: Effects of feedstocks and pyrolysis temperature on biochar properties." *J. Environ. Qual.*, 41(4), 990-1000.

Kookana, R. S., Sarmah, A. K., Van Zwieten, L., Krull, E., and Singh, B. (2011). "Biochar application to soil: Agronomic and environmental benefits and unintended consequences." *Adv Agron*, 112, 103-143.

Lucchini, P., Quilliam, R. S., DeLuca, T. H., Vamerali, T., and Jones, D. L. (2013). "Increased bioavailability of metals in two contrasting agricultural soils treated with waste wood-derived biochar and ash." *Environ Sci Pollut R*, 1-11.

Meyer, W., Seiler, T.-B., Reininghaus, M., Schwarzbauer, J., Püttmann, W., Hollert, H., and Achten, C. (2013). "Limited waterborne acute toxicity of native polycyclic aromatic compounds from coals of different types compared to their total hazard potential." *Environ Sci Technol*, 47(20), 11766-11775.

National Research Council (NRC), (2002). *Biosolids applied to land: Advancing standards and practices*. Committee on Toxicants Pathogens. National Academy Press.

Oleszczuk, P., Jośko, I., and Kuśmierz, M. (2013). "Biochar properties regarding to contaminants content and ecotoxicological assessment." *Journal of Hazardous Materials*, 260(0), 375-382.

Reddy, K.R., Yargicoglu, E.N., Yue, D., and Yaghoubi, P. (2014a). "Enhanced microbial methane oxidation in landfill cover soil amended with biochar." *Journal of Geotechnical & Geoenvironmental Engineering*, In Print.

© ASCE 2014

Reddy, K.R., Xie, T., and Dastgheibi, S. (2014b). "Evaluation of biochar as a potential filter media for the removal of mixed contaminants from urban stormwater runoff." *Journal of Environmental Engineering*, In Print.

Singh, B., Singh, B. P., and Cowie, A. L. (2010). "Characterisation and evaluation of biochars for their application as a soil amendment." *Soil Research*, 48(7), 516-525.

Spokas, K. A., Cantrell, K. B., Novak, J. M., Archer, D. W., Ippolito, J. A., Collins, H. P., Boateng, A. A., Lima, I. M., Lamb, M. C., McAloon, A. J., Lentz, R. D., and Nichols, K. A. (2012). "Biochar: A synthesis of its agronomic impact beyond carbon sequestration." *J Environ Qual*, 41(4), 973-989.

Spokas, K. A., Novak, J. M., Stewart, C. E., Cantrell, K. B., Uchimiya, M., DuSaire, M. G., and Ro, K. S. (2011). "Qualitative analysis of volatile organic compounds on biochar." *Chemosphere*, 85(5), 869-882.

Xie, T., Reddy, K.R., Wang, C., Yargicoglu, E., and Spokas, K. (2014). "Characteristics and applications of biochar for environmental remediation: a review." *Critical Reviews in Environmental Science & Technology*, In Print.

Yaghoubi, P. (2011). *Development of biochar-amended landfill cover for landfill gas mitigation*. Ph.D. Thesis, University of Illinois at Chicago, Illinois, United States.

© ASCE 2014

Thinking Inside the Box: Modular Energy Systems for RE < C

Dan Millison[1]

[1] Transcendergy, LLC, 108 Montague Circle, Williamsburg VA 23185, PH (757) 565-2070, email: danmillison@gmail.com

ABSTRACT

The rapid decline in costs of solar photovoltaic (PV) systems and wind power are due largely to expanded manufacturing capacity, technological advances, and an important but mostly overlooked aspect: the modular nature of these systems, which facilitates "plug and play" construction, quick start up, and staged expansion. Modular build-out allows for much smaller start-up investment and earlier revenue realization compared to conventional centralized generation plants, a critical consideration in developing countries. Alternatively stated, the modular approach avoids the "too big to succeed" syndrome associated with gigawatt (GW) scale centralized power plants in developing countries where financing constraints result in long gestation periods, projects that never reach fruition, and other "fat tail" outcomes (Ansar, A., et al. 2013).

The reality is that for most of the one billion or so people in the world who are not connected to the grid today, the centralized generation model will never work. Rapid expansion of mass production capacity (a "Model-T" approach) is critical to deliver renewable energy (RE) at parity with coal (C), thus, accelerated development of modular systems is an attractive pathway to achieving "RE<C" but requires a fresh look at economic assumptions underpinning project development. Modular systems can be scaled up for large grid-connected projects and can also be scaled down to provide energy access to bottom-of-the-pyramid consumers. The modular approach can be applied to water supply and wastewater treatment, which have also suffered from the "too big to succeed" syndrome in developing countries.

Introduction

As technological advances and policy shifts have encouraged the development of renewable energy (RE) systems, providing sustainable energy for all has become an important and achievable mission. In the context of this goal, a key challenge is to accelerate RE deployment at scale while lowering costs. Mass production of RE technology is needed to produce power at parity with coal (C), eventually reaching "RE < C." The rapid decline in solar photovoltaic (PV) and wind power hardware costs is due to expanded manufacturing capacity as well as the modular "plug and play" nature of these systems. As of 2012, solar PV module costs were expected to decline 22% for each doubling of capacity; wind power costs have declined less rapidly, but in many countries wind power is already competitive with fossil-fired electricity (IRENA, 2012).

© ASCE 2014

For the purposes of discussion, "modular" is defined by four characteristics: (i) mass-production in factories or other manufacturing facilities; (ii) "plug and play" architecture, i.e., a simple kit that is easy to install and operate; (iii) transportability, preferably using standard inter-modal shipping containers; and (iv) speedy delivery and construction, e.g., 12-24 months from ordering to commissioning. Lofty predictions of eliminating global poverty by 2030 are underpinned by an implicit assumption that access to energy will not be a constraint to poverty reduction. Modular energy systems offer the combination of scale, speed, and cost reductions that will be required to meet energy for all objectives.

For most of the one billion or so people in the world who are not connected to the grid today, the centralized generation model will never work. Annual growth rates for grid electrification are improving. For example, electrification rates in India, Indonesia and the Philippines -- home to about 400 million people without grid-supplied electricity -- have reached 2% per year (World Bank Global Electrification Database, 2012). This expansion rate suggests that universal electrification can be achieved within the next few decades assuming that technical, physical, and financial barriers can be eliminated. Unfortunately, the simple arithmetic of expanding centralized grids is misleading: although the "last mile" of the system continues to be extended, there is in fact a "last mile" of the grid beyond which geographic realities such as mountain ranges and archipelagos intrude. Acknowledging the limits of centralized electricity grids, the International Energy Agency estimates that to achieve universal access to electricity, 70% of rural areas that currently lack access will need to be connected using mini-grid or off-grid solutions (IEA, 2010).

Time Travel and Re-inventing History

If Alexander Graham Bell were alive today he would not recognize the telecommunications business, but if Thomas Edison were alive he would most certainly recognize the grid. As the technology and regulatory policy evolution that occurred in the telecoms business is showing some signs of life in the energy business, a brief review of the early history of the electricity business is in order.

One of Thomas Edison's main financial backers, J.P. Morgan, had a vision of community-owned combined heat and power plants, not unlike today's concept of distributed generation. But in the late 19th and early 20th century, wood and coal were the most readily available fuels for Edison's electric "dynamos," which were noisy, dirty, and generally not user-friendly to the urban customers of the time. Edison himself had a monopolistic streak which was embraced by one of his business managers, Samuel Insull, who introduced the concept of the "natural monopoly" in 1892, arguing that competition among companies building and operating duplicate transmission and distribution systems was economically inefficient. This logic was compelling for the wires business, enough so that Insull was able to implement his vision (the operative word being "monopoly") for the entire electricity supply chain which included creation of independent electricity regulators and subsequent regulatory capture. Eccentrics such as Nikola Tesla who argued for conservation of

© ASCE 2014

coal and wood in favor of electric motors driven by water, wind and sun, were not able to present a sufficiently robust alternative vision, and for well over a century the centralized generation and grid model has dominated energy planning, regulation, development, and economics. [The foregoing summary is consolidated from Goodell, 2006.]

Today this centralized generation model persists in the form of the supply side, least-cost, economy-of-scale approach which works from resources to consumers; this model generally points to coal-fired power and large hydropower as least-cost solutions. This traditional model assumes that there are no supply chain constraints, no financing constraints, no coal price volatility, no exchange rate risk, and no environmental externalities (similar assumptions are made for gigawatt-scale hydropower projects). As long as these primary assumptions prevail, coal-fired power can be delivered at a theoretical wholesale cost of $0.05 – 0.06 per kilowatt-hour (kWh); among developing countries these assumptions have prevailed only in China, with catastrophic environmental and public health consequences. As noted above, the reality is that for most of the one billion or so people in the world who are not connected to the grid today, the centralized generation model will never work.

Working from consumers back towards resources, a different picture emerges: for un-served and under-served consumers, the most readily available electricity typically comes from diesel- or gasoline-fired generator sets at a cost of $0.25/kWh or higher, which is more expensive than every form of commercial RE kit today. When the reality of $0.25/kWh petroleum-based electricity is acknowledged by policy- and decision-makers, then a mix of energy efficiency (EE) and RE can be delivered at parity with coal (EE + RE < C). RE-based modular systems, including micro- and mini-grids, are now an obvious solution for energy access for bottom-of-the-pyramid consumers (IEA, 2010). Expanded manufacturing and deployment of modular systems is expected to drive down system costs further which will improve the financial viability of modular systems for large grid-connected projects. This concept is of considerable interest for next-generation nuclear power, and is also gaining traction in the form of floating liquefied natural gas facilities.

Back to the Future

In order to deliver power to under-served and off-grid consumers while protecting public health and preserving ecosystem integrity, it is essential to expand global investment in sustainable energy from hundreds of billions of dollars per year to more than a trillion dollars per year. Something other than the centralized generation business model is needed and there are 3 examples for ready reference: (i) J.P. Morgan's original vision, noted above; (ii) the evolution of networked PCs complementing mainframe computers; and (iii) mobile telecommunications, which is arguably the single greatest infrastructure success in recorded human history; everyone in the world who wants a cell phone already has one, in part due to the advent of pay-as-you-go cellular phone services. Complementing these business models, modular energy systems are already available in the form of solar photovoltaic (PV), biomass energy, heat recovery power generation, battery-based

© ASCE 2014

energy storage, and wind power (although transportability can be an issue for large wind units). Solar and wind are up- and down-ward scalable, and all of these technologies are appropriate for distributed generation applications and can be readily deployed in micro- and mini-grids. To achieve the trillion dollar investment scale required, a "model-T" approach is needed to remove capital cost barriers and deliver affordable energy services to the average person; the challenge is to translate the pre-paid mobile phone model to other infrastructure services. Conceptually, the marriage of available business models and modular energy technologies can address the global energy for all development challenge, but an additional step is required to ensure *sustainability*.

In the context of utility-scale grid-connected operations, baseload and quasi-baseload solutions are needed for grid stability, reliability, and power quality. Variable output RE, e.g., solar PV and wind power, are problematic in this context and must be coupled with energy storage and smart grid technologies for optimization. Until the cost of energy storage and smart grids declines by an order of magnitude or more, a key challenge and opportunity for sustainable energy services is to adapt modular design to hydropower, concentrating solar thermal power (CSP), and geothermal power, which address traditional utility preferences for baseload and dispatchable power. This is a significant challenge as essentially every utility-scale hydro, CSP, and geothermal plant worldwide has been custom-designed to site-specific hydrological, meteorological, and geological conditions. For each of these sub-sectors, at least 2 examples of modular approaches have been identified, which are discussed briefly below.

Hydropower

Modular hydropower utilizing 1 and 2 MW containerized units is being deployed in a commercial project which is part of a 50 megawatt (MW) hydropower development program in Honduras (Central America Data, 2011). The first stage is an installation of four 1 MW containerized generation units which are being retrofit to an existing 22.5 MW run-of-river plant (Stover, 2013). The basic layout is shown in Figure 1. The installed cost is estimated at $1.20/watt, all-inclusive. The project has a simple, "plug and play" architecture, and is expected to be completed in less than two years from ordering to start-up. This project is the first commercial prototype for the containerized generation units developed by pHp International, and if successful will be technically applicable to other hydropower rehabilitation and upgrade projects using a modular kit.

A second example of modular hydropower technology is the 50 MW Ashta project in Albania. This project utilizes prefabricated turbine-generator packages which are about the size of a telephone booth (http://www.andritz.com/hy-hydromatrix). The units are designed for low-head conditions with application mainly via retrofit of existing dams and other flow control structures not originally designed for power generation. The Ashta project was completed in a little over 30 months (www.energji-ashta.al), which is quite fast for a hydropower project of this scale. The

© ASCE 2014

capital cost is $4.6/watt with a levelized cost of electricity (LCOE) of $0.082/kWh (Sobek, 2013).

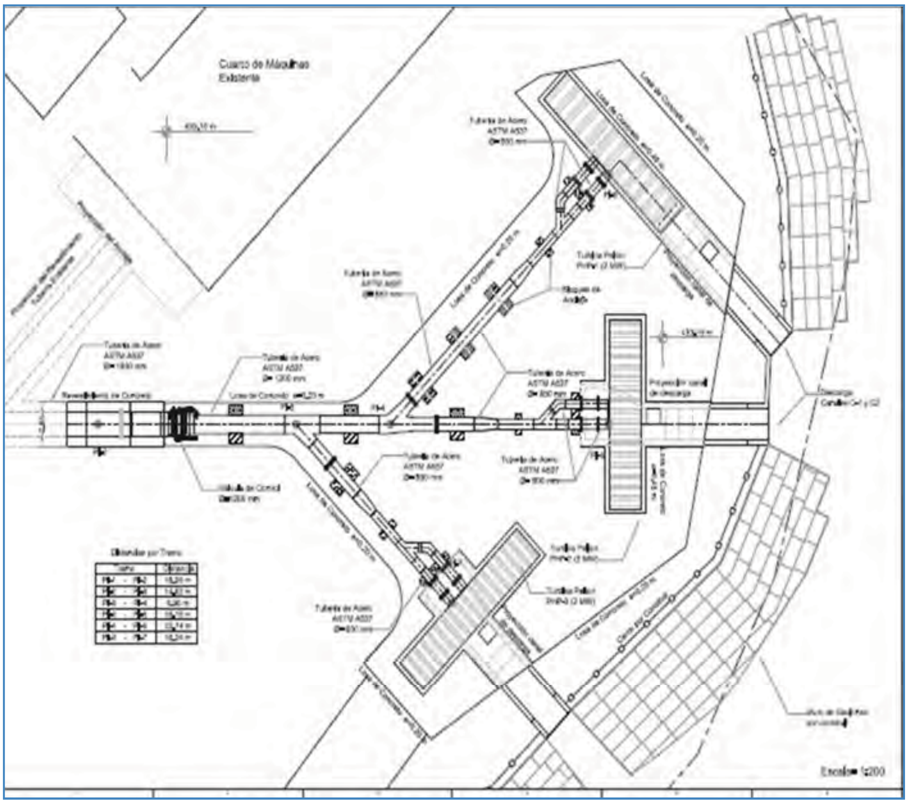


Figure 1: Modular Hydropower Design (graphic courtesy of pHp Energy International)

CSP

Although more attractive for utility-scale applications than PV, CSP technologies are much more complex than PV, which begs the question: can CSP be built at “Model-T prices” by scaling up hardware production, or is “Tesla X” the best price we can expect? Like hydropower, CSP development has been dominated by one-off designs customized to specific sites. At least two modular CSP technologies have been fielded on a commercial basis: the Stirling Dish-Engine and the eSolar modular tower system. A third modular system with integral thermal storage is being pioneered by Solastor of Australia (solastor.com.au).

The Stirling Dish-engine features a dish-shaped solar collector reflecting energy to a central receiver mounted on the dish, supported on a structure with 2-axis tracking (the units resemble small radio-telescopes). The receiver drives a Stirling engine with nominal capacity is 25 kW; energy conversion efficiency of up to 32% is the highest demonstrated CSP technology (e.g., parabolic trough and tower technologies have conversion efficiencies of 15-16%). Although an elegant piece of technology, the dish-engine has struggled to gain market share. The main technology vendor, Stirling Energy Systems, was founded in 1996 and developed a commercial project in Maricopa County, Arizona. Stirling Energy Systems filed for chapter 7

© ASCE 2014

bankruptcy in September 2011. The Maricopa County project was acquired by United Sun Systems which continues to develop the technology.

The modular tower design concept is notable as it is intended specifically to deliver CSP in Model T mode: eSolar of California was founded by former information technology (IT) professionals with an interest in quantum advances in RE commercialization, and operates on the concept of melding IT and advanced energy technology (the success of the mobile telephony business model applies). The eSolar kit generated plenty of "buzz" when the company's prototype plant was commissioned in early 2011: the plant was constructed in less than 12 months from ground-breaking to initial generation, which is probably a record for any infrastructure project in modern-day California. Only 1 other project is known to be using the eSolar technology, which is a 10 MW project in India (as of February 2014, the first 2.5 MW module was operational). The eSolar installed cost appears to be lower than any other utility-scale solar technology including thin-film PV, as shown in Table 1.

Table 1: Recent Landmark Solar Projects

Project / Technology	Capacity (MW)	Total Cost ($)	LCOE ($ / kWh)
Morocco Ourzazate / Trough with 3 hours storage	160	2.8 billion	0.19
Chile Atacama / Tower with 8 hours storage	50	425 million	[to be determined after tendering]
Reliance Power / CLFR	100	415 million	0.21
Dahanu / Thin film PV	40	147 million	0.36
Acme / eSolar modular towers	10	29.9 million	n/a

Installed costs on the projects shown in Table 1 vary dramatically, which is to be expected based on the variety of technologies and project scales. The modular tower system has the lowest installed cost of approximately $3/watt, while the projects with thermal storage are estimated at $8.5/watt for Atacama and $17.5/watt for Ourzazate. The Reliance and Dahanu projects are at the lower end of the range with $4.15 per watt and $3.68 per watt, respectively. The LCOEs should be viewed with caution as these are site-specific and will vary with the cost of financing: the 3 projects in India are being financed on a commercial basis, while the projects in Chile and Morocco enjoy substantial concessional financing from various donors and the Clean Technology Fund; it remains to be seen whether a large CSP project like Ourzazate can achieve LCOE of less than $0.20/kWh without concessional financing. [The $0.20/kWh benchmark is used as this was the average of wholesale tariffs bid for 7 private sector CSP projects in phase 1 of India's National Solar Mission.]

© ASCE 2014

The Solastor CSP system comprises modules with 1 MWh electricity output generated from 3 MWh of heat energy with integral graphite energy storage. Each module requires about 0.25 hectares of land. The system is designed to deliver electric power 24 hours per day, and is upward scalable. The design is less complex than the current generation CSP plants using molten salt for energy storage. As of early July 2014, Solastor had 4 pioneering projects under development; the largest is a 25 MW installation in Cyprus.

Geothermal

Geothermal energy is the only RE resource that reliably delivers baseload power on a "24/7/365" basis, but like hydropower and CSP, geothermal projects are designed to specific sites due to geological and geophysical realities. The typical project development cycle entails at least 3 years of exploration and development drilling (overlapping with power plant design), followed by 3 years of construction; an 8 to 9 year lead time is not uncommon before any electricity and revenue are generated. Two modular design concepts are being developed and deployed, both using wellhead generation units which can be installed as soon as a well has been completed. Both concepts are similar to a networked PC design versus conventional mainframe computers, with modular generation units installed at the well-head to begin generating power as soon as possible. This design obviates the need to drill several wells before designing a steam gathering system and centralized power plant.

Modular generation units ranging from about 3 – 6 MW capacity have been deployed in the US, New Zealand, and Kenya with promising results. A pilot project in Kenya is being scaled up to 75 MW which will be the world's largest project using this design approach (Sutter, *et al*, 2012). Figure 2 illustrates the comparative development time frames for conventional versus modular concepts, with the modular approach generating power and revenue by year three of operations, as opposed to year nine with the traditional model.

Figure 3 illustrates that additional power output for a theoretical 50 MW geothermal project could be as much as 1,500 GWh. The financial advantages of this additional output will depend on project specifics, but assuming an off-take price of $0.10/kWh (for ease of arithmetic) the additional revenue would be $150 million. Applying an industry rule-of-thumb of $4-5/watt, this additional revenue represents 60-75% of the all-inclusive installed cost of a 50 MW project. In the absence of carbon finance or other policy instruments which might monetize the life-cycle economic benefits of geothermal power, the modular design approach bears further attention.

The second modular geothermal concept is intended for development of lower-grade resources using a closed-loop-in-ground heat exchange design, coupled to a binary generation unit at the wellhead. This design concept is based on "heat mining" rather than steam or brine production: no fluid is produced, so the impact on groundwater flow is much less than conventional steam/brine production, and this system could open up geochemically-hostile thermal resources for commercial

© ASCE 2014

development. Asian Development Bank funded a preliminary feasibility study on a project in the Philippines, but no sites have been designated for development and the project has not moved forward. This system has not been demonstrated at scale and is considered pre-commercial.

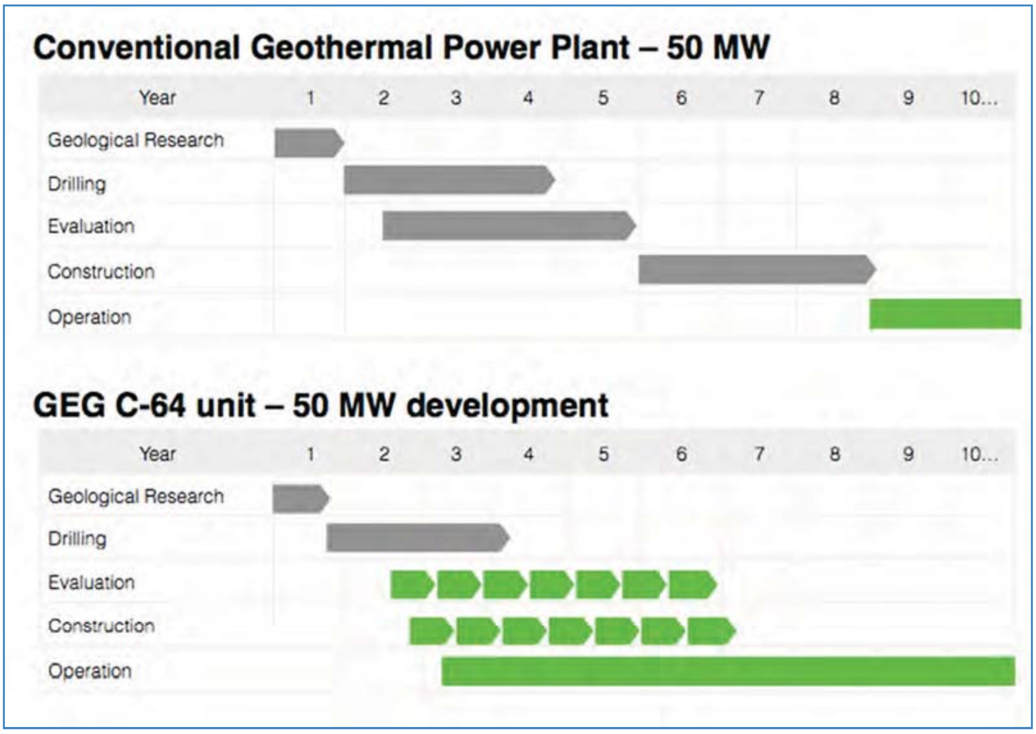


Figure 2: Comparative Geothermal Development Timelines (graphic courtesy of Green Energy Group AS)

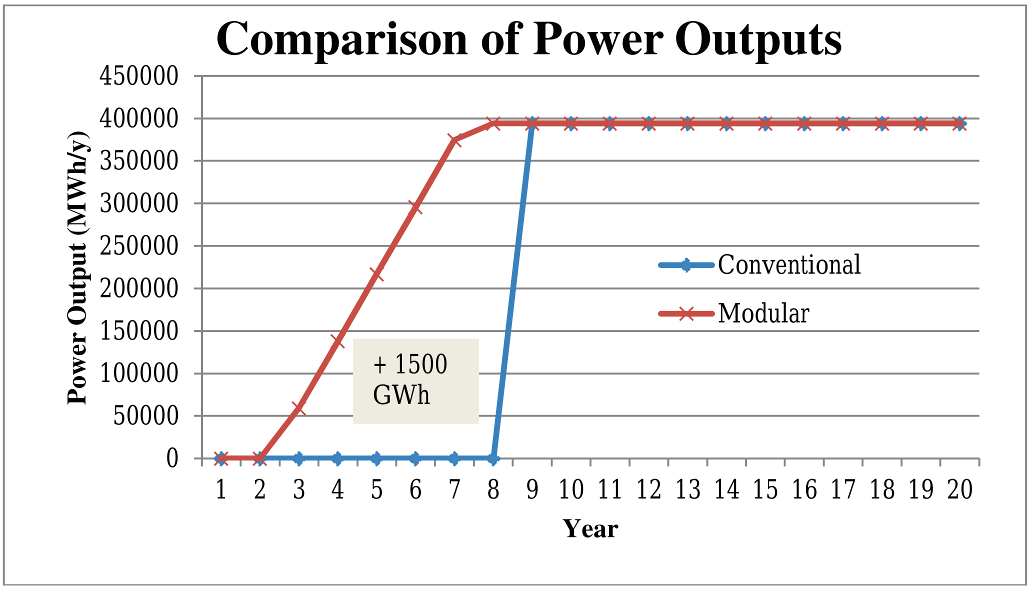


Figure 3: Comparative Generation Output (graphic courtesy of Green Energy Group AS)

© ASCE 2014

Outlook

As modular RE development moves forward, there are financing challenges and development issues that must be addressed. Modular development cannot remove all of the inherent geophysical, technical, and other development risks associated with utility scale CSP, geothermal, and hydropower development. E.g., costs and risks for diversion structures, channels, and tunnels remain site-specific for each project, but powerhouse design and capital costs can be reduced. Upfront exploration and development drilling risks are inherent in geothermal power development, but early revenue generation with modular wellhead units could improve the financial viability of otherwise marginal prospects. Modular systems do allow increased flexibility for project development by reducing the scale of upfront capital expenditures, avoiding the "too big to succeed" problem often seen in GW scale power plants in developing countries. Modular systems also offer the prospect of leveraging developer equity for multiple small projects instead of one large project, spreading development risks. More importantly, modular systems offer the prospect of deployment via pay-as-you go business models analogous to mobile telephony.

Modular energy system deployment should be viewed in the broader context of the nascent disintermediation of the traditional centralized utility business. J.P. Morgan's vision of community-owned DG is being actively re-imagined: David Crane, the president and chief executive officer of NRG, the largest independent power producer in the US, recently noted that there is an "*inexorable trend towards a distributed generation-centric, disaggregated future featuring individual choice and the empowerment of the American energy consumer. That this future is going to occur is, in my opinion, inevitable;* ***that it's going to occur faster than almost every person thinks it's going to occur is highly probable***." (NRG Conference call, 2014). Crane's point was punctuated in late May 2014, when Barclays's downgraded bond ratings for the US electric utility industry, noting: "*we believe that a confluence of declining cost trends in distributed solar photovoltaic (PV) power generation and residential-scale power storage is likely to disrupt the status quo*."

Crane's outlook is well-founded considering the rapid cost declines and attendant growth in solar PV capacity worldwide during the last several years, and the potential for rapid cost declines for modular energy storage which is expected to result from Tesla Motor's "gigafactory" (which will produce advanced batteries for 500,000 electric vehicles per year by 2020; this annual output will be more than total global lithium-ion battery production in 2013). "CSP in a box" may never materialize, because if PV costs continue to decline and if energy storage costs continue to decline, then low-cost CSP may not be necessary (rapid PV cost declines arguably bankrupted the Stirling dish-engine company). The implications should not be overlooked: solar energy is the most abundant clean energy resource in the world: with an estimated 85,000 terawatts of potential, it is more than 850 times more abundant than all other renewable resources combined (Abbott, 2010), and is more than 5000 times total world power consumption *circa* 2010 (see figure 4). Today, in the second decade of the third millennium, the prospect of solar power that is "too

© ASCE 2014

cheap to meter" coupled with affordable energy storage is being advanced by entrepreneurs in defiance of Samuel Insull's 100 year old business model. Skeptics of this outlook are reminded to look at their handheld supercomputer (colloquially referred to as a "smart phone") which was delivered to them at a price well below the actual cost of production.

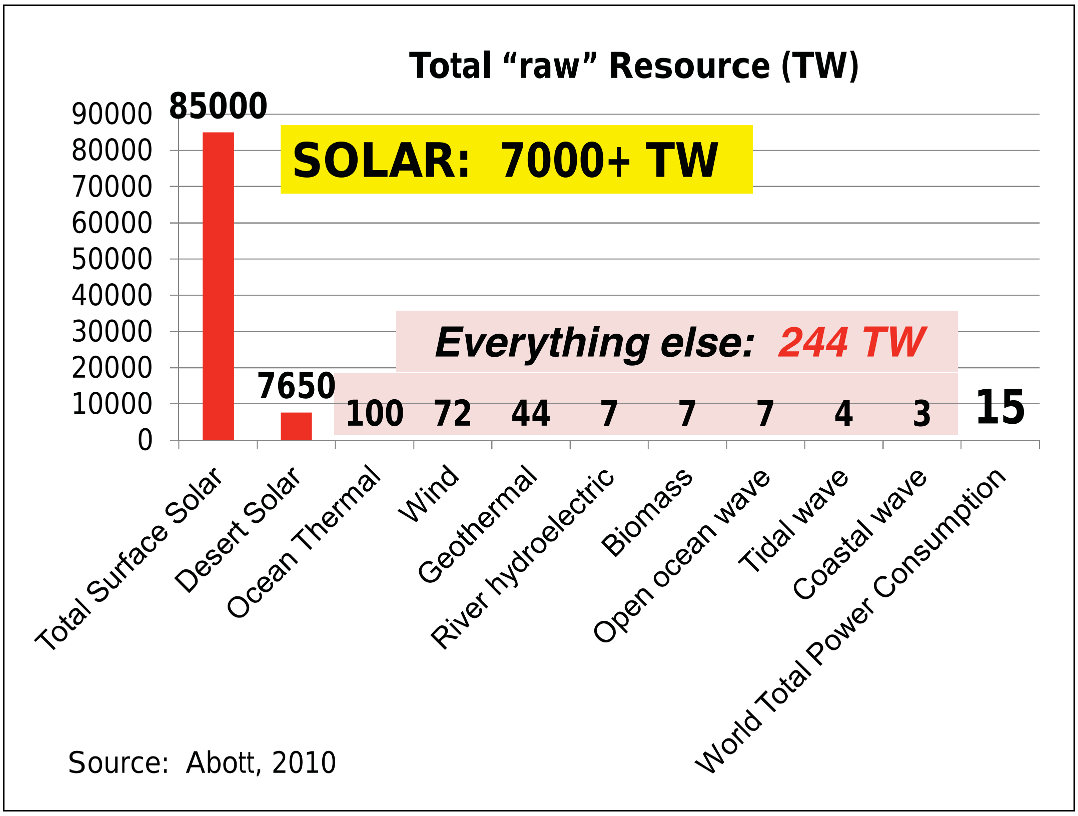


Figure 4: Comparison of Global Renewable Energy Resource Potentials

Conclusion

As the center of global economic growth shifts to Asian cities, it is not at all obvious that centralized infrastructure models will support the evolution of sustainable cities. Alternatively stated, cloning western infrastructure design approaches in developing countries has not worked: aside from some successes in the Asian tiger economies, the system is broken and it does need to be fixed. In this 21st century context, a focus on "bottom-of-the-pyramid" consumers is necessary to facilitate equitable economic growth and political stability in developing countries. These socio-economic development challenges can be met by mass production of "power in a box" and "micro-grids in a box" which can be dropped in to under-served and un-served areas including rapidly growing urban areas with inadequate infrastructure. Modular energy systems can be complemented by modular water supply and "sewer in a box" wastewater treatment systems which can be community-owned and operated. In order to provide sustainable infrastructure for all, developers need to think outside the box… about what can be put inside a box. As a dividend,

© ASCE 2014

with continued technology improvements and cost reductions, in the foreseeable future we can envision a mix of EE, RE, and energy storage (S) at parity with coal -- EE + RE + S < C -- which spells "victory" in the war on climate change.

References

Abbott, Derek. 2010. "Keeping the Energy Debate Clean: How Do We Supply the World's Energy Needs?" *Proceedings of the IEEE* 98, no.1.

Atif Ansar, Bent Flyvbjerg, Alexander Budzier, and Daniel Lunn. 2013. "Should we build more large dams? The actual costs of hydropower megaproject development." Energy Policy (2014), http://dx.doi.org/10.1016/j.enpol.2013.10.069i

Asian Development Bank. *45927-012: Single Well Engineered Electrical Turbine System (Sweets) Geothermal Power Project*. Asian Development Bank. Accessed on 6 March 2014 from: http://www.adb.org/projects/45927-012/details

Central America Data. 2011. *Honduras Seeks Solutions to Energy Crisis*. September 22, 2011. Accessed on 6 March 2014 from: http://www.centralamericadata.com/en/article/home/Honduras_Seeks_Solutions_to_Energy_Crisis

Goodell, Jeff. 2006. *Big Coal: The Dirty Secret Behind America's Energy Future*. Houghton Mifflin, Boston/New York.

International Energy Agency, 2010. *Energy Poverty – How to make access to energy universal?* IEA. Paris.

International Renewable Energy Agency (IRENA). 2012. *Renewable Power Generation Costs in 2012: An Overview*. IRENA. Abu Dhabi.

NRG Energy Inc. (NRG) Q4 2013 Earnings Conference Call February 28, 2014. Accessed online 7 March 2014 from: http://seekingalpha.com/article/2059563-nrg-energys-ceo-discusses-q4-2013-results-earnings-call-transcript

Sutter, Joel, Ezekiel Kipyego, and Dominic Mutai. 2012. *The Use of Portable Geothermal Wellhead Generators as Small Power Plants to Accelerate Geothermal Development and Power Generation in Kenya*. GHC Bulletin, February 2012.

Sobek, Martin. 2013. *IFC's support to power sector PPPs in Europe and Central Asia*. Presentation at Asia Clean Energy Forum, Manila. June 2013.

Stover, Mark. 2013. *National Congress of Honduras Approves 4 MW Run-of-River Hydropower Development Involving Hydro Green Energy*. January 18, 2013. Accessed on 6 March 2014 from: http://www.hgenergy.com/El%20NisperoApprovalFinal.pdf

© ASCE 2014

Additional References on Wellhead Geothermal

Hanson, Stephanie. December 14 2011. *Full Steam Ahead: Kenya's Geothermal Production Picks Up Speed*. GE.http://www.ecomagination.com/full-steam-ahead-kenyas-geothermal-production-picks-up-speed March 7, 2014.

Geirdal, Carlos Atli Cordova. January 2013. *Economic Comparison Between a Well-head Geothermal Power Plant and a Traditional Geothermal Power Plant*. Reykjavik University. Accessed on 6 March 2014 from: http://skemman.is/stream/get/1946/14017/33257/1/Economic_Comparison_between_a_Wellhead_Geothermal_Power_Plant_and_a_Traditional_Geothermal_Power_Plant.pdf

Special thanks are due to the following exerts who provided details on modular energy systems:

Michael Bass, eSolar
Paul Bulson, DalcoPoint
Peiter de Vries, PT Contained Energy Indonesia
John Lerch & John Alcordo, GE
Mory Houshmand & Thomas Spignesi, Catalyst Energy Technologies
Mark November, pHp Energy International
Alex Richter, Green Energy Systems AS

© ASCE 2014

Minimization of CO_2 Emissions for Spread Footings under Biaxial Uplift Using a Big Bang-Big Big Crunch Algorithm

Andrew Assadollahi[1], Ph.D., E.I. and Charles V. Camp[2], Ph.D.

[1] Assistant Professor, Department of Civil and Environmental Engineering, Christian Brothers University, Memphis, TN 38104; email: aassadol@cbu.edu
[2] Professor, Department of Civil Engineering, The University of Memphis, Memphis, TN 38152; email: cvcamp@memphis.edu

ABSTRACT

A procedure is developed to minimize CO_2 emissions for the design of reinforced concrete spread footings subjected to biaxial bending satisfying both geotechnical limit states and structural requirements using a Big Bang-Big Crunch (BB-BC) algorithm. The objectives are to minimize CO_2 emissions and compare designs developed for loading outside of the kern area with analysis procedures when loading is within the kern area. The CO_2 emissions are associated with the extraction and transportation of raw materials; processing, manufacturing, and fabrication of products; and the emissions of equipment involved in the construction process. The CO_2 objective function is subjected to soil bearing and displacement limits, as well as bending moment, shear force, and reinforcing details specified by the American Concrete Institute (ACI 318-11). A design example is presented to compare low-CO_2 emission designs when detachment of the soil from the footing occurs to low-CO_2 emission designs when the entire base of the footing is in compression. Results are presented that demonstrate the effects of different magnitudes of eccentricities on designs.

INTRODUCTION

According to the United Nations Intergovernmental Panel on Climate Change (UNIPCC 2007), there has been a significant increase in the build-up of global greenhouse gases (GHG) in the atmosphere due to human activities since the pre-industrial times. The production of Portland cement, the principal binder used in concrete, is responsible for large emissions of carbon dioxide (CO_2) (Mehta 2002). Due to increased demand for concrete products and structures, the carbon footprint of the cement industry almost doubled between 1990 and 2005 (Mehta 2009). As a result of the concerns of the increased levels of GHG, design and construction methods have moved towards more sustainable materials, designs, and construction practices. In addition, there has been no investigation into the comparison of spread footing designs based on simplifying analysis procedures with theoretical analysis procedures for low-CO_2 emissions, subjected to biaxial bending, which consider all of the geotechnical and structural limit states using evolutionary methods.

Biaxial bending occurs when the applied force acts through a point displaced from the center along both of the principal directions. In this case, there are two

© ASCE 2014

eccentricity values, which are the perpendicular distances from the center of the footing to the applied load. For moment loading; there are two applied moments, each about one of the principal axes. In practice, there are many simplifying analysis procedures that are made in the design of spread footings which yield conservative, over-designed results. If CO_2 emissions associated with the design and construction of the spread footing are of significant concern, using simplifying analysis procedures which yield over-designed footings and result in increased CO_2 emissions may not be desired. In practice, a common simplifying assumption that is often made is the entire base of the footing is to be in compression.

Big Bang-Big Crunch (BB-BC) has been shown to be a computationally efficient heuristic method to solve a variety of optimization problems. Erol and Eksin (2006) proposed the original BB-BC algorithm, which involved exploiting the power of the mean of a population using an abstract model of the lifecycle of the universe. In each "Big Bang" stage, a set of normally distributed solutions is generated about the weighted mean of the solution space. After the solutions are evaluated, a "Big Crunch" stage computes a new center for the next "Big Bang" based on the fitness of the various solutions. Over successive cycles of Big Bangs and Big Crunches, the standard derivation of the normal distribution of new solutions decreases and the search tends to become more localized in the neighborhood of the best solution. When some measure of the averaged solution and/or the best solution ceases to improve over a number of cycles, the optimization is assumed to have converged.

The form of the objective function for this optimization is consistent with that presented by Camp and Assadollahi (2013). The CO_2 emission objective function includes the unit emissions associated with excavation, formwork, reinforcing steel, concrete, and compacted backfill.

The general form of the optimization problem is given as

$$\textit{Minimize:} \quad f_{CO_2} = \sum_{i=1}^{R} E_i u_i \left(x_1, x_2, ..., x_n \right) \tag{1}$$

$$\textit{Subject to:} \quad p_j \left(x_1, x_2, ..., x_n \right) \le 0 \tag{2}$$

where f_{CO_2} is the CO_2 emission function, E_i are the unit CO_2 emissions, u_i is the amount of material and construction units, x_i are the design variables, n is the number of design variables, R is the number of material and construction units, and p_j are the penalty functions.

SPREAD FOOTINGS SUBJECTED TO BIAXIAL ECCENTRIC LOADING

Biaxial eccentric loading is encountered when an applied force acts through a point displaced from the center of the footing along both of the principal directions or there are two applied moments, each about one of the principal axes. During eccentric loading, a non-uniform bearing pressure distribution is produced. Figure 1 shows a schematic of a spread footing subjected to biaxial loading where the origin is taken to be the center of the footing and the applied force is P, the length of the footing is L, the width is B, the eccentricity along the x-axis is e_x, and the eccentricity along y-axis

© ASCE 2014

is e_y. Due to symmetry, only positive eccentricities are considered.

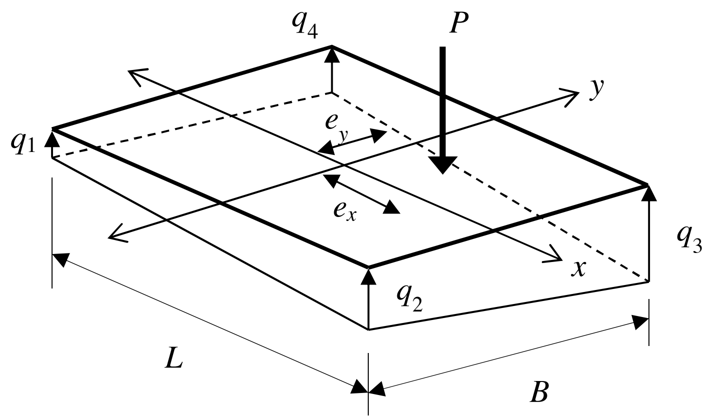


Figure 1. Spread Footing Subjected to Biaxial Loading.

When a footing is subjected to biaxial loading and there is no detachment of the soil (the entire bearing surface is in compression), loading will be within the kern area and the well-known bending formula is applied to determine the bearing stresses at the four corners of the footing as

$$q_{[1-4]} = \frac{P}{BL}\left(1 \pm \frac{6e_y}{B} \pm \frac{6e_x}{L}\right) \quad (3)$$

When Equation (3) equals zero, the kern boundary is:

$$\frac{6e_y}{B} + \frac{6e_x}{L} = 1 \quad (4)$$

Therefore, when the left side of Equation (4) is larger than 1, a portion of the footing will become detached from the soil, assuming that the soil cannot support tension, and Equation (3) is no longer applicable for determining the bearing pressures at the four corners of the footing.

Analytical solutions for the case of biaxial uplift will be based upon the formulation for a rectangular element with associated interpolation functions. The choice of a rectangular element formulation is made because the analysis of only rectangular spread footings is considered in this research.

© ASCE 2014

A general relationship for the bearing pressure surface beneath a rectangular spread footing as

$$q(x,y)=\frac{q_1}{BL}\left(y-\frac{B}{2}\right)\left(x-\frac{L}{2}\right)-\frac{q_2}{BL}\left(y-\frac{B}{2}\right)\left(x+\frac{L}{2}\right)+\frac{q_3}{BL}\left(y+\frac{B}{2}\right)\left(x+\frac{L}{2}\right)-\frac{q_4}{BL}\left(y+\frac{B}{2}\right)\left(x-\frac{L}{2}\right) \quad (5)$$

Depending on where the load is located with respect to the kern boundary, only Corner 1 may become detached (Case 1), Corners 1 and 4 may become detached (Case 2), Corners 1 and 2 may become detached (Case 3), or Corners 1, 2, and 4 may become detached (Case 4). Different sets of boundary conditions are applied to Equation (5) for each of the four cases of biaxial uplift. In addition, integral equations are utilized with different boundary conditions and are applied to Equation (5) for the evaluation of punching shear, one-way shear, and flexural analysis in the concrete section.

SIMPLIFIED ANALYSIS PROCEDURES

In practice, there are several simplifying assumptions in the analysis procedures that are implemented for footings subjected to biaxial loading. Four of them are considered in this study.

1) The punching shear force through the footing is taken as the factored applied axial load.
2) The one-way shear through the footing and the moment produced at the column face due to the soil pressure is based upon the maximum bearing pressure value, q_{max}.
3) The development length of the flexural steel in the footing is placed along both directions of the footing, less the clear cover.
4) Eccentricities greater than the kern area are not permitted.

Based on the analysis results using these simplifying assumptions, the size of the footing and reinforcement requirements are determined. While an over-designed foundation provides additional safety against ultimate limit state and service limit state failures, there is an increase in CO_2 emissions associated with the extra materials. For engineers or clients who are striving to be environmentally friendly, theoretical analysis procedures are utilized for the design of spread footings subjected to biaxial bending, within or outside the kern, that more accurately describe the bearing pressure distribution beneath the footing. A comparison is made between designs developed from the simplified analysis procedures and those developed from the theoretical analysis procedures that are derived from applying different boundary conditions to Equation (5).

© ASCE 2014

LIMIT STATES

Geotechnical limit states include soil bearing capacity and foundation settlement. For bearing capacity analysis, the effective area method is used (Meyerhof 1953). Vertical and rotational elastic settlements are given by Poulos and Davis (1974). The structural limit states are provided by ACI 318-11 and include: two-way (punching) shear capacity of the footing; one-way shear capacity for each dimension of the footing; flexural capacity for each dimension of the footing; maximum and minimum spacing requirements in both directions of the footing; minimum reinforcing steel requirements; maximum strain limits in the tension steel in both directions; bearing capacity of the column, dowels, and footing; and reinforcing steel development length requirements.

DESIGN VARIABLES

Figure 2 shows the design variables for the spread footing model. There are four geometric design variables representing the dimensions of the footing: the dimension of the footing in which the eccentricity is parallel to is $B_1 = x_{min} + X_1$ (x_{min} is the larger of the width of the column b_1 and $3e$). The dimension of the footing perpendicular to this is $B_2 = x_{min} + X_2$ (x_{min} is assumed to be the width of the column b_1). The depth from the ground surface to the bottom of the footing is $D = X_3$, and the thickness of the footing is $H = T_{min} + X_4$ (T_{min} is assumed is the sum of 76.2 mm concrete cover below the reinforcement and 152.4 mm concrete cover above the reinforcement). There are six design variables related to the steel reinforcement of the various sections of the footing: R_1 is the bar number in the long direction of the footing, R_2 is the number of bars in the long direction of the footing, R_3 is the bar number in the short direction of the footing, R_4 is the number of bars the short direction of the footing, R_5 is the bar number of the dowels, and R_6 is the number of dowels. S_1 is the compressive strength of the concrete.

CONSTRAINTS

In order to provide safety and stability against geotechnical and structural limit state failure, constraints are imposed to ensure stability of the geomaterial and concrete capacity, as well as reinforcement configuration and geometric limitations. Each design constraint is posed as a penalty on the overall objective function of the design and is non-zero only when violated. Therefore, if the design is feasible, the sum of the constraint penalties will be zero. There are 36 different penalties that are imposed on designs when a constraint is either less than a minimum requirement or greater than a maximum requirement. The general form of a penalty equation for maximum constraint values is:

$$p_{max} = 1 - \frac{constraint_{max}}{constraint} > 0 \tag{6}$$

The general form of a penalty equation for minimum constraint values is:

$$p_{min} = 1 - \frac{constraint}{constraint_{min}} > 0 \tag{7}$$

© ASCE 2014

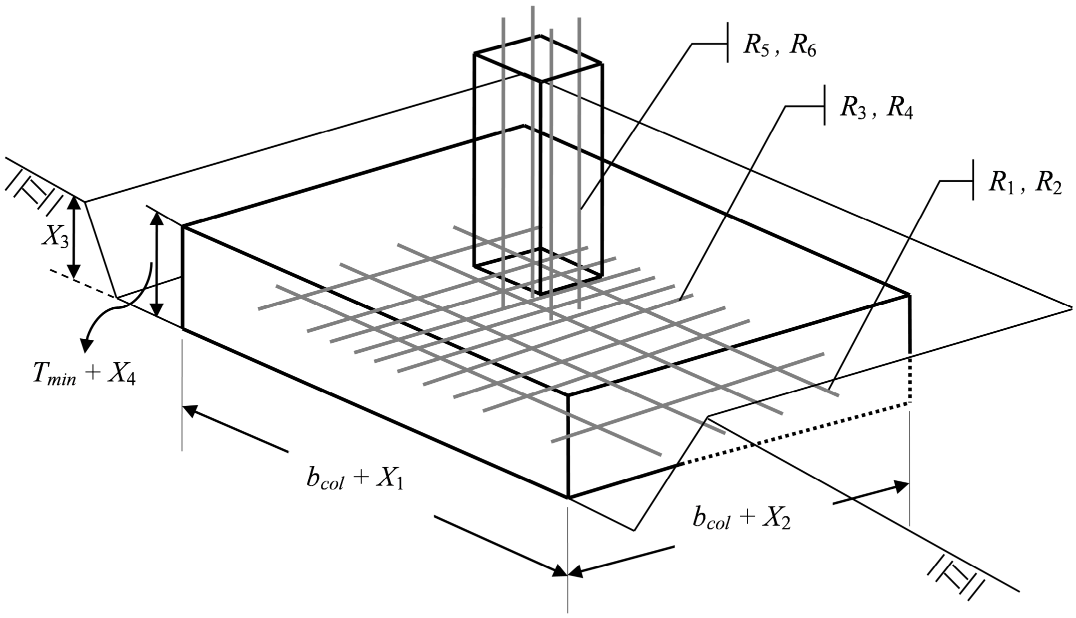


Figure 2. Design Variables for Spread Footing Model.

An additional penalty is developed for the footing designs using the simplified analysis procedures. This penalty does not allow for footing detachment from the soil, as this is typically not allowed in practice. A total penalty function is used to enforce the penalties p_j on the objective function. The total penalty for a candidate low-CO_2 emission design k is a function of the summation of the stability, capacity, reinforcement configuration, and geometric constraints.

The penalized objective function F_k is a product of the CO_2 objective function of candidate design k and its total penalty:

$$F_k = \left(1 + \sum_{j=1}^{36} p_j\right)^{\eta} f_k \tag{8}$$

where η is a positive penalty exponent. The penalty function imposes a numerical penalty on the value the objective function that tends to reflect the degree at which the constraints are violated by a candidate set of design variables.

BIG BANG-BIG CRUNCH OPTIMIZATION

Erol and Eksin (2006) developed the original BB-BC optimization from an abstract model of the lifespan of the universe. In the initial Big Bang stage, solution variables are uniformly randomly distributed throughout the search space. Next, during the contraction of the Big Crunch stage, a center of mass $\vec{x}_{cm}$ is computed from the initial population using penalized objective function values as

© ASCE 2014

$$\vec{x}_{cm} = \frac{\sum_{k=1}^{NC} \frac{\vec{x}_k}{F_k}}{\sum_{k=1}^{NC} \frac{1}{F_k}} \tag{9}$$

where $\vec{x}_k$ is the position of candidate k in an n-dimensional search space and NC is the candidate population size. For the subsequent iterations of the Big Bang stage, new candidate solution positions $\vec{x}_k^{new}$ are normally distributed around the center of mass by

$$\vec{x}_k^{new} = \beta_1 \vec{x}_{cm} + (1-\beta_1)\left[\beta_2 \vec{x}_l + (1-\beta_2)\vec{x}_g\right] + \frac{r\alpha(\vec{x}_{max} - \vec{x}_{min})}{n_{cycle}} \tag{10}$$

where β_1 and β_2 are values in the range [0, 1] that weight the influence of the local best solution $\vec{x}_l$ and the global best solution $\vec{x}_g$ on the center of mass of new population positions; r is a random number from a standard normal distribution, α is a parameter limiting the size of the search space, $\vec{x}_{\max}$ and $\vec{x}_{\min}$ are the upper and lower limits on the values of the design variables, and n_{cycle} is the number of Big Bang iterations. Depending on where the center of mass is located in the search space, especially during early cycles of the algorithm, it is possible to generate a design variable value that is outside the prescribed range. In this case, values that lie outside the search space limits are reset to the appropriate minimum/maximum values (Erol and Eksin 2006). The global best solution $\vec{x}_g$ is limited to candidates that are feasible, in other words, designs that have no penalty applied to their objective function values.

Numerical results indicate that a population of 300 candidate solutions is adequate to balance computational efficiency and overall algorithm performance. A general stopping criterion of 2,000 analyses is used. Computational results show that $\beta_1 = 0.3$, $\beta_2 = 0.6$, and $\eta = 2$ routinely provide the best footing designs for this example. Using a value of $\alpha = 1$ in Equation (10) enables the initial search to sample the full range of values for each design variable.

DESIGN EXAMPLE

The objective of this design example is to investigate CO_2 emission impact between using the theoretical analysis procedures and simplified analysis procedures for the design of spread footings subjected to biaxial bending. All designs will satisfy geotechnical limit states, as well as the ACI 318-11 requirements for reinforced concrete.

The fitness function is defined as

$$f_{CO_2} = E_e V_e + E_f A_f + \xi E_r M_r + \frac{f_c'}{f_{c\,\min}'} E_c V_c + E_b V_b \tag{11}$$

where E_e is the unit emission of excavation, E_f is the unit emission of formwork, E_r is the unit emission of reinforcement, E_c is the unit emission of concrete, E_b is the unit emission of backfill, ξ is scale factor that gives the reinforcing steel term a magnitude

© ASCE 2014

comparable to that of the other terms and is taken as 10 in study; $f'_{c\min}$ is the minimum allowable strength of concrete and is taken as 20 MPa. The computation of the volume of excavation V_e, area of formwork A_f, mass of the reinforcement M_r, volume of concrete V_c, and volume of compacted backfill V_b is consistent with the methodology used by Camp and Assadollahi (2013).

Unit emission values are based on extraction and the transportation of raw materials; processing, manufacturing, and fabrication of products and machinery; and the emissions of equipment involved in the construction process and are given in Camp and Assadollahi (2013). Table 1 lists the specified footing and soil design parameters. Table 2 lists the summary of the low-CO_2 emission designs developed by the BB-BC procedure. On average, there is a 63.7% savings in CO_2 emissions when the theoretical analysis procedures are used. All material quantities are significantly less when the theoretical analysis procedures are used; most notably, there is approximately 88% less rebar and 98% less backfill in the design based on the theoretical analysis procedures.

A sensitivity study is done by varying the applied column eccentricities. Figure 3 shows a surface plot of the difference between average CO_2 emission values of designs based on the simplified analysis procedures and the theoretical analysis procedures. The general trend shows that as the eccentricities increase, the difference in CO_2 emissions increases dramatically. For $e_x = e_y = 1$m, it is seen that over 16,000 kg of CO_2 can be saved if the simplified analysis assumptions are not made and theoretical analysis procedures are used. Figure 4 shows a surface plot of the percentage of detached area as a function of eccentricities. For $e_x = e_y = 1$m, the BB-BC algorithm produces feasible designs that allow over 14.5% of the footing area to be detached from the soil.

© ASCE 2014

Table 1. Input Parameters.

Input parameter	Unit	Symbol	Value
Internal friction angle of soil	degree	ϕ'	35
Unit weight of soil	kN/m^3	γ_s	18.5
Poisson Ratio of soil	—	ν	0.3
Modulus of elasticity of soil	MPa	E	50
Applied vertical force	kN	P	3,000
Over excavation length	m	L_o	0.3
Over excavation width	m	B_o	0.3
Factor of safety for bearing	—	FS	3.0
Maximum allowable settlement	mm	δ	25
Applied Moment about *x*-axis*	kN-m	M_x	3,000
Applied Moment about *y*-axis*	kN-m	M_y	3,000
Unit weight of concrete*	kN/m^3	γ_c	23.56
Modulus of elasticity of steel*	GPa	E_s	199.95
Column length*	mm	l_{col}	457.2
Column width*	mm	b_{col}	457.2
Concrete Cover in Footing*	mm	*cover*	76.2
Minimum Footing Thickness*	mm	T_{min}	228.6

Note: All values given by Wang and Kulhawy (2008) except for * values which

© ASCE 2014

Table 2. Designs Based Low CO_2 Emissions.

Design Variables	Simplified Analysis	Theoretical Analysis
X_1 (m)	3.50	2.24
X_2 (m)	3.58	2.24
X_3 (m)	2.73	0.34
X_4 (m)	1.39	0.98
R_1	9	7
R_2	31	31
R_3	8	7
R_4	39	31
R_5	11	4
R_6	12	12
S_1 (MPa)	20	25
B	6.50	5.24
L	6.58	5.24
H	1.62	1.21
Region	kern	A
Detached Area (m^2)	—	3.98
Detached Percent	—	14.5 %
Excavation (m^3)	127.720	10.435
Concrete Formwork (m^2)	42.343	25.332
Reinforcement (kg)	2,118.037	257.114
Concrete (m^3)	68.958	33.153
Compacted Backfill (m^3)	58.260	1.100
Best CO_2 Emission	25,041.20 kg	9,279.84 kg
Average CO_2 Emission	27,415.41 kg	9,939.03 kg
Std. Dev. CO_2 Emission	1,426.30 kg	413.03 kg
Average No. Analyses	25,304	23,424

© ASCE 2014

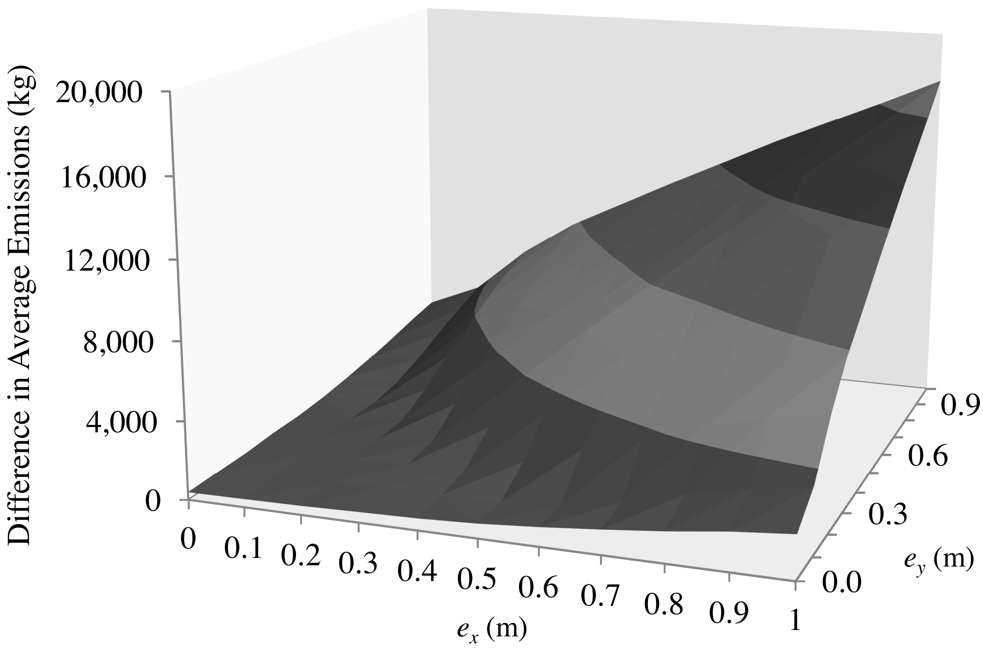


Figure 3. Difference in CO_2 Emissions between Simplified and Theoretical Analysis Procedures.

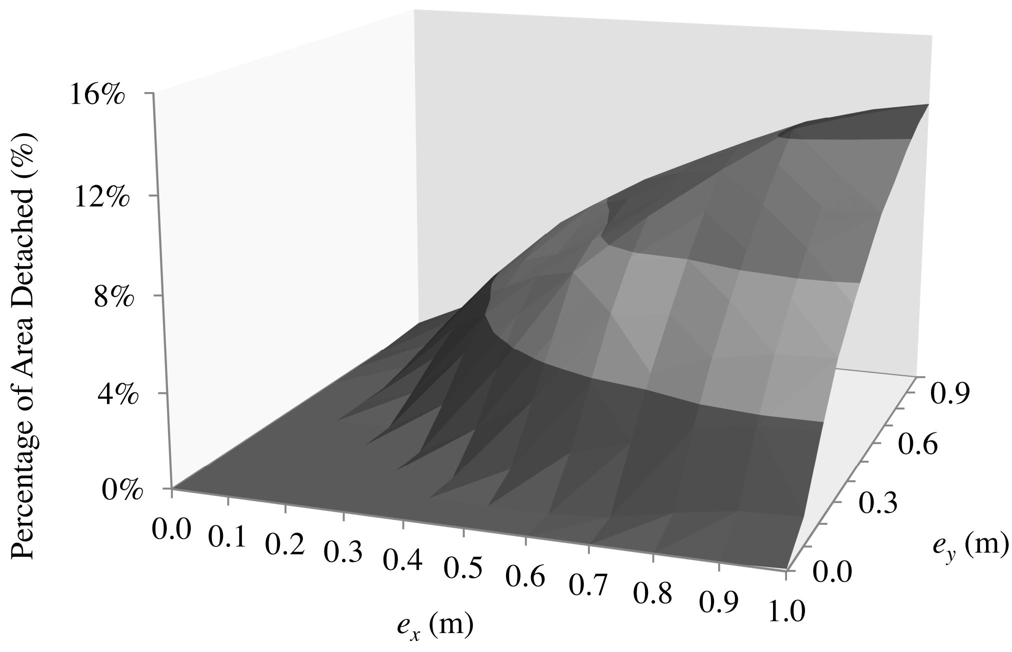


Figure 4. Average Percentage of Detached Area of Biaxial Loaded Footing.

© ASCE 2014

CONCLUSIONS

A comparison is made between reinforced concrete spread footing designs using simplified assumptions, commonly made in practice, with theoretical analysis procedures. Evaluations are based on design optimizations using a CO_2 emission objective function developed with a hybrid multi-phase BB-BC algorithm. Design examples show that there is a significant savings in CO_2 emissions for designs based upon theoretical analysis procedures when compared to designs based upon simplified assumptions. A sensitivity analysis shows a significant increase in CO_2 emissions between designs using the simplified assumptions and those using theoretical analysis procedures as the loading and eccentricities increase. For designs with 3,000 kN of applied load at $e_x = e_y = 1$m, the percent detachment is as high as 14.5%.

REFERENCES

American Concrete Institute (2011). ''Building Code Requirements for Structural Concrete and Commentary.'' ACI 318-11.

Camp, C. V. and Assadollahi, A. (2013). "CO_2 and Cost Optimization of Reinforced Concrete Footings Using a Hybrid Big Bang-Big Crunch Algorithm." *Structural and Multidisciplinary Optimization*, available online: http://link.springer.com.

Erol, O. K. and Eksin, I. (2006). "A New Optimization Method: Big Bang-Big Crunch." *Advances in Engineering Software*, Vol. 37, 106-111.

Mehta, P. K. (2002). "Greening of the Concrete Industry for Sustainable Development" *Concrete International*, July, 23-28.

Mehta, P. K. and Merman, H. (2009). "Tools for Reducing Carbon Emissions Due to Cement Consumption" *Structure*, January, 11-15.

Meyerhof, G.G. (1953). "The Bearing Capacity of Foundations Under Eccentric and Inclined Loads'" *Proceedings, 3rd International Conference on Soil Mechanics and Foundation Engineering*, Vol. 1, p. 440 – 445, Zurich.

Poulos, H. G. and Davis, E. H. (1974). "Elastic Solutions for Soil and Rock Mechanics." *Wiley, New York*.

United Nations Intergovernmental Panel on Climate Change (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

© ASCE 2014

Development of Adaptation Framework for Climate Change Engineering Assessment of Transportation Assets

Amit Armstrong[1], Michael Flood[2], and Michael Meyer[3]

[1]Technology Deployment Program, Western Federal Lands Highway Division, Federal Highway Administration, 610 E 5th St, Vancouver WA 98661; PH (360) 619-7668; FAX (360) 619-7846; email: amit.armstrong@dot.gov

[2] Parsons Brinckerhoff, 100 S. Charles Street, Tower 1, 10th Floor, Baltimore, MD, 21201; (410) 727-5050; email: flood@pbworld.com

[3] Parson Brinckerhoff, 3340 Peachtree Rd, NE, Suite 2400, Tower Place 100, Atlanta, GA 30326; PH (678) 984-8521; FAX (404) 237-3015; email: meyer@pbworld.com

ABSTRACT

System resiliency of transportation infrastructure is a growing concern of transportation professionals for both longer term risks associated with climate change and in response to extreme weather events. This paper presents a prioritization framework and case study addressing climate change adaptation for transportation infrastructure. This framework is based on (1) Outcomes of a series of engineering assessments to identify implications of incorporating climate variability in projects already completed/underway; (2) Development of policies for including risk as part of decision-making in planning and engineering; (3) Development of methods by which to prioritize improvements to reduce / eliminate risks to the existing network; and (4) Development of methods by which to incorporate climate change / extreme weather into decision-making for planning and engineering projects. Based on temporal distribution of expected climate change and observed issues, potentially at-risk facilities are identified. This framework also includes design life of transportation facilities, replacement cost values and an assignment of loss scores for damage/loss value – all of which are utilized in a benefit/cost framework. This general framework can be customized by various agencies by redefining their priorities and addressing risks.

INTRODUCTION

Transportation infrastructure adaptation to long-term changes in climate and to short-term risks associated with extreme weather events has been a growing concern to transportation officials. Evidence of such changes and risks has been found throughout the world, with transportation systems in particular considered to be especially vulnerable. A recent report from the Transportation Research Board, for example, summarized the different types of climate-related stresses that could impact

© ASCE 2014

transportation facilities and systems. (Meyer et al, 2014) An illustration of these stresses and their impacts includes:

Change in extreme maximum temperature

- Premature deterioration of infrastructure.
- Damage to roads from buckling and rutting.
- Bridges subject to extra stresses through thermal expansion and increased movement.
- Safety concerns for highway workers limiting construction activities.
- Thermal expansion of bridge joints, adversely affecting bridge operations and increasing maintenance costs.
- Vehicle overheating and increased risk of tire blowouts.
- Rising transportation costs (increase need for refrigeration).
- Materials and load restrictions limiting transportation operations.
- Closure of roads because of increased wildfires

Additional stresses that were examined in this study included: change in range of maximum and minimum temperatures, greater changes in precipitation levels, increased intense precipitation, other change in storm intensity (except hurricanes), sea-level rise and increased hurricane intensity.

The interest in enhancing transportation system resiliency in light of potential climate-related risks is found in many state efforts, for example, (California Natural Resources Agency, 2009; California Department of Transportation, 2011; Maryland State Highway Administration and Maryland Transportation Authority, 2012; Vermont Agency of Transportation, 2012; Virginia DOT, 2011; Washington State DOT, 2011, 2012); in city and regional planning agency activities (City of Toronto, 2011; Metropolitan Transportation Commission, 2011; North New Jersey Transportation Planning Authority, 2011); federal agency initiatives (FHWA, 2012; FHWA et al, 2011; ICF International and Parsons Brinckerhoff, 2011; and U.S. Army Corps of Engineers, 2011) and in professional or industry transportation organizations (Meyer, Choate and Rowan, 2011; Wall and Meyer, 2013; and Meyer, Rowan Savonis and Choate, 2012). In many cases, climate adaptation and enhancing system resiliency has been championed in other countries much earlier and in more advanced ways than what has been found in the U.S. [see, for example, (Black et al, 2010; Commonwealth of Australia, 2006; Highways Agency and Parsons Brinckerhoff, 2008; and PIEVC and Engineers Canada, 2008).

One of the primary goals in each of these efforts was to identify either a decision framework that could be used to identify the most cost effective decisions for reducing climate-related risk, or to provide an assessment of likely climate-related risks (and to let such information be used as desired within the existing decision making process). However, many of these efforts have run into challenges with respect to how one defines climate-related risks, how one considers the future benefits of mitigating potential problems with today's dollars, and how climate-related mitigation priorities can be identified in today's investment programs.

© ASCE 2014

The purpose of this paper is to describe a decision-making framework for adaptation planning for individual assets that could also be used to determine priorities among assets at a subarea level. It should be noted at the outset that the following process would likely be used only for those assets or facilities which are considered critical to a region's transportation system, such as a major bridge, major highway, lifeline road, airport, port or trunk transit rail line. Undertaking this process for assets of lesser importance can certainly occur, but it is not likely that transportation agencies will spend the time and resources to conduct this type of analysis for all of its assets. The final section of the paper suggests a way of expanding the adaptation decision-making process to a larger number of projects.

DECISION-MAKING FRAMEWORKS FOR INVESTMENTS IN ADAPTATION STRATEGIES

A systematic process should be used to conduct engineering analysis of adaptation options for improving the resilience of transportation infrastructure to climate change and extreme weather events.(Meyer and Weigel, 2011) The following steps provide a consistent process for doing so:

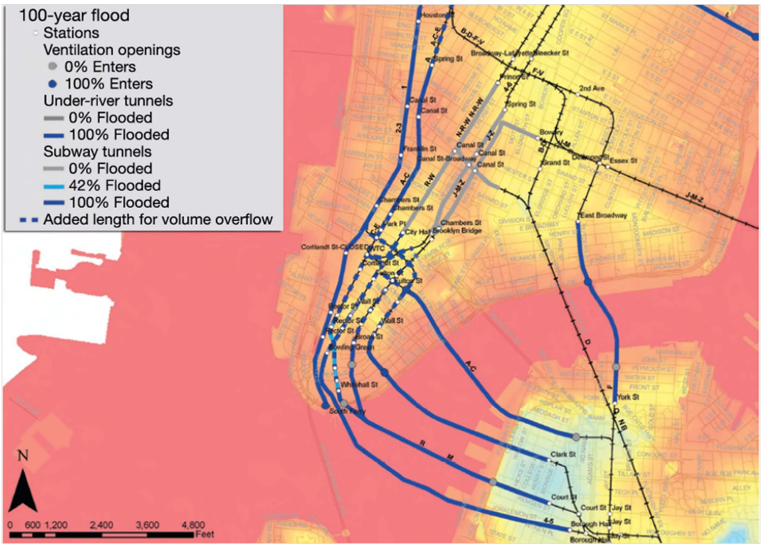
1. Identify the physical limits of the asset and what is to be analyzed.

Identifying the limits of project-related impacts from extreme weather events and assessing the physical characteristics, such as topography and surrounding area, of the identified assets becomes an important first step in adaptation planning. Mapping and analysis would provide first indications of the physical limits of the assets that need to be analyzed. Historical and modeled climate scenarios could then be used to decide if areas beyond past damage limits would be vulnerable to inundation. The process would culminate in a sensitivity analysis of the vulnerability of the assets to future damage from a variety of climate scenarios—both historic and future.

A 2011 study of the likely flood impacts of a 100-year coastal storm on the transportation systems serving the greater New York City metropolitan area provides an example of Step 1. Based partly on modeling of the opening cross sections of underground transport systems, including vent openings, subway entrances and rail road and roadway tunnel entrances at low elevations, the study computed the time it would require, and the extent of tunnel flooding, as a function of the rising and retreating flood water head above the various openings of the underground transportation systems. (Jacob et al, 2011) The forecasts (an example is shown in Figure 1) were verified by Hurricane Sandy in surprising detail. Such an analysis delineated the boundaries of the impact area associated with storm surge as they related to subway lines.

2. Clearly identify the climate variables to be examined and the mechanisms by which the climate variable can damage the asset (e.g. wave action on bridge decks, roadway embankment failure due to high velocities associated with weir overtopping flow, softening/rutting of asphaltic pavements due to vehicle loading combined with extended high temperatures, etc.)

© ASCE 2014



Source: LDEO/Civil Engineering, Columbia University; ClimAD, Chapter 9, page 311, Figure 9.11A, Jacob et al. 2011

Figure 1: Example of a Forecast for NYC Subway Tunnel Flooding for a Coastal Storm Surge with a 1%/year Probability (annual chance of 1/100) for downtown Manhattan and adjacent East River crossings into Brooklyn.

A thorough understanding of the specific climate variables that influence the engineering of transportation facilities is crucial to understanding how climate change will impact transportation assets. Figure 2 shows how "Rainfall Intensity/Frequency Increase" can affect various infrastructure components. The far right column lists a reference to formulae and variables that would be required to assess the possible effects. Similar tables could include the effects of temperature increase, sea level rise and storm surge.

This step in the analysis helps determine how climate conditions might shape the designs of the assets being investigated in an engineering assessment. Understanding how climate variables can damage infrastructure and how climate has shaped the design of various transportation assets enables us to determine how those designs might be threatened when climate changes or extreme weather events occur.

3. Identify design criteria and standards currently used to design the asset.

One of the first steps in analyzing potential impacts to an asset is to compare current design features of the asset to future stresses to that design. This requires one to know present-day design criteria and standards. This task involves not only identifying the applicable criteria, but also collecting that data from the various infrastructure owners, engineering or public works departments.

In many cases these standards are the same for more than one jurisdiction (for example, the highway design criteria and standards for a turnpike authority might be

© ASCE 2014

Environmental Factor	Facility	Possible Effect	Cause	Factors that Influence Change	Formulae
Rainfall Intensity/Frequency Increase	Roadway Foundation	Foundation weakening	Saturation		300, 301
			Erosion		
			Groundwater elevation increase		301, 301
		Foundation and roadway loss	Flooded culvert or bridge failure		300, 301
	Roadway Pavement	Surface deterioration	Base and subbase saturation		
		Surface loss	Flooded culvert failure		100-108
	Roadside Slopes	Slope failure	Erosion		302
			Soil saturation		302
	Roadside Planting	Species growth	Hydration		
	Bridge - Water Crossing	Structural damage	Scour (erosion)		100-108
			Water load		202
			Soils pressure change		
	Bridge - Roadway Crossing	Structural damage	Soils pressure change		
	Culvert	Structural damage	Erosion		
		Failure	Floodwater erosion		
			Buoyancy		
	Storm Sewerage	Surcharge	High runoff rate	Runoff rate	100
	Open Channel	Flooding	High runoff rate	Runoff rate and velocity	100-108
		Failure	Erosion from high runoff rate and/or volume	Runoff rate and duration	101-108
		Stream migration	Erosion from high runoff rate and/or volume	Runoff rate, duration, volume	100-008

Figure 2: Illustrative Relationship Between Rainfall Intensity/Frequency and Design Parameters

the same as for a state DOT). In many cases, however, the design standards not only vary from asset to asset, but also vary within the same asset category depending on functional classification. For example, the hydraulic performance of a bridge varies depending on the functional classification of the road it serves. In the case of this engineering-based adaptation assessment process, understanding design standards is critical.

4. Determine whether the asset meets current design criteria/standards. What is required to bring the asset to meet current standards?

Design criteria and standards set the level of expectation for a particular asset's performance. The most recognizable example would be the designation of storm frequency---the 10-year storm or the 100-year storm. The resulting performance of a particular asset designed for say the 10-year storm sets a level of expectation of how well drainage systems must perform. Comparing this level of performance with the asset's performance under possible future scenarios provides a metric with which to measure the necessity of adaptation procedures.

Step 3 identified current design standards and requirements for the selected asset or infrastructure component. Once the limits of the asset study area are determined and the range of future climate stressors defined, it becomes a direct engineering exercise to compare the conformance of an asset's site-specific components to the current design criteria and determine their threshold of tolerance to the level of stress predicted. For example, for a drainage structure or bridge over a waterway, an engineering team could perform planning–scale hydrologic and

© ASCE 2014

hydraulic analyses to evaluate asset components and determine if the asset meets the current standards. Any deficiency will be identified and summarized. Older bridges, for example, may not meet the current design standards and would be even more vulnerable to climate change effects.

Once a deficiency is identified, one could investigate possible flexible adaptation measures to not only "bring the asset to meet current standards," but to look at future performance as well, since current standards are not likely to account for future weather events of greater intensity. At this point, the engineering-based adaptation process will focus on making the design of the adaptation measures at a level sufficient to determine a "planning-level" construction cost. The costs of these designs would then be examined against the costs of failure of the asset (see Step 8). The results of this analysis would then be the first step in settling on the design solution.

5. Identify relevant climate data applicable to engineering analysis. If exact data required for design cannot be obtained from climate modeling, how can the readily obtainable data be used in the analysis? Is there an alternative design method that can be substituted or a data surrogate that could be used? Also include discussion of uncertainty and appropriate level of risk based on traffic, criticality, current development, and examination of check floods.

Climate scenarios range in scale and severity. In most engineering-based adaptation assessments there will be gaps in the data needed to perform the analyses that the owners and the design team would desire. An engineering team might very well investigate available models, and other relative climate data such as the output from the National Oceanic and Atmospheric Administration (NOAA) and the US Geological Survey (USGS). Criteria for selecting climate data could focus on the availability of the data, its reliability (compared to other models), its length of record, and resolution of scale. It should be noted that climate models do not predict exact data for design. Changes and ranges of changes are predicted by the models for severe storm frequencies, rainfall intensity and frequency, sea level rise, and temperature.

In some cases, climate scientists are able to provide climate projections directly from climate models with a reasonable degree of certainty in a format useful to engineers. However, this is not always the case as sometimes the temporal or spatial resolution of the climate model outputs are too coarse and/or uncertain relative to what is needed by designers. One example of this is the projection of precipitation depths for periods less than 24 hours in duration, a key input for the designs of drainage infrastructure in small catchments.

Realizing that today's climate models are not always capable of providing the detailed site-specific information needed by engineers, it is important to consider alternative design approaches that can be used to work around some of these challenges. Design reference tables, or example, could list data surrogates available for each climate variable input where a specific climate projection may not be readily available from climate models. (Meyer et al, 2014) In other cases, the design process itself can be altered to accommodate the uncertainty in future climate. This is a key

© ASCE 2014

component of the flexible design approach whereby one designs in the flexibility to make further design changes to a facility if and when conditions warrant. Such an approach can be useful where there is a sense that a climate variable may change in some way but there is a lack of understanding in exactly how much it might change.

6. Develop a reasonable range of climate scenarios to analyze.

The uncertainty and range of prediction of climate models are wide, but becoming more refined. Before climate data was available, even to the level it now is, planners and engineers recognized the need to address environmental changes in some manner. Without the benefit of reliable climate change data, some elected to increase the design input (e.g., rainfall intensity) by a somewhat arbitrary factor that might range as high as 10 percent above the historic data. For relatively smaller assets, this "arbitrary" increase might actually benefit the asset because of the additional level of protection.

However, one would want to know which model data were available for design variables, perhaps develop a comparison table and recommend a range of scenarios. A key consideration would be to understand which forecasts are more reliable than others (e.g., temperature forecasts tend to be more reliable than precipitation forecasts). Of course, the data inputs into the engineering formulae are fairly specific in terms of what inputs are necessary, which means that climate scenarios could be used to define ranges of input values associated with design parameters.

Another approach that might be considered is the so-called "bottom-up" approach. In this approach, the lower limit of failure would in essence establish the threshold value of the input variables. If the respective values of the range of this variable fall below this threshold, then little or no adaptation effort is needed. If, on the other hand, the threshold is reached, engineering judgment would be used to determine what level of input value would be used in comparison to the climate scenario-determined values.

7. Identify design thresholds and perform a sensitivity analysis of which design standards are violated by which climate variables.

From step 4, the performance of each of the selected transportation assets will be determined under existing conditions to define the limits of its capability to perform its function. The same asset, e.g., a bridge, would be evaluated against the future climate parameters (variables) under each of the climate change scenarios to determine if the functional design criteria will be met. Sensitivity analyses and the associated risk would be performed by using a "what-if" or "degree of certainty" approach.

Once a deficiency is identified, possible flexible adaptation measures could be developed to not only "bring the asset to meet current standards," but to look at future performance as well, since current standards are not likely to account for future weather events of greater intensity. The costs of these designs will be examined against the costs of failure of the asset (see Step 8). The results of this analysis will be the first step in settling on the design of a solution.

© ASCE 2014

8. Perform an economic analysis that includes present worth of the capital cost, maintenance, failure replacement cost, damage cost, and economic loss of each design option

Many of the agencies currently considering adaptation strategies are first asking, "what are the benefits of making such an investment?" To conduct asset-specific economic analyses, an engineering team would have to have access to engineering economy-type models or approaches. Thus, the discussion for this step will necessarily be general enough to cover different approaches for conducting an economic analysis. Two perspectives on economic analysis will be covered: the economic costs associated with the asset itself, that is, capital, maintenance, replacement and damage costs; and the potential economic losses associated with each design. This latter economic loss is one that relates directly to the ability of each design option to avoid further loss related to climate change or extreme weather events (which is thus considered a benefit).

The first type of costs is illustrated by the COAST (COastal Adaptation to Sea level rise Tool) model, which evaluates relative risk-mitigation benefits of sea level rise and storm surge adaptation planning strategies. It is in use with a wide array of vulnerable assets, including real estate values and economic activity, but in transportation settings it has particular utility. It operates by calculating of cumulative expected damages to an asset over a multi-decade period, given user-specified sea level projections and storm surge intensities and recurrence intervals (Kirshen et al. 2012). Central to the calculations is a depth-damage function that specifies the amount of lost value at different depths of inundation. For transportation asset repair or replacement, these functions are derived for each candidate design structure. Costing inputs include user-specified net present value parameters (discount rates), changes in real value of the assets versus inflation, and discounted construction, maintenance, and replacement or repair costs. Cumulative expected damage calculations then allow comparison of costs (installation and maintenance, discounted) versus benefits (avoided damages or catastrophic failures) over a multi-decade period, providing a robust means of evaluating the long-term cost-efficiencies of candidate design structures, under a range of anticipated environmental conditions. This approach has been proven on >100'-span bridges in the state of Maine.

For the second type of economic loss, one needs to account for transportation-related economic benefits of each design option. This assessment will focus on avoidance (or reduction) of loss of transportation service and capacity, and will estimate the transportation and associated economic benefits (i.e., avoided costs) resulting from reduction of harm to transportation assets and corresponding loss of transportation service. Key metrics will include those often found in transportation benefit/cost (BCA) and economic impact studies. The former will include travel time savings, reductions in transportation congestion of key facilities, reduced vehicle operating costs for transportation assets that remain in service, and various environmental and other external benefits associated with increased highway VMT. This type of economic loss could be too involved for many transportation agencies. For example, methods to estimate the transportation impacts of network-level disruptions would require a variety of techniques, including potential use of the

© ASCE 2014

regional travel demand. Wider economic impacts from loss of access to employment by workers, or loss of freight access, would also have to be estimated. Such losses would include loss of economic productivity and output resulting from restrictions on access by workers to job sites, inability of firms to conduct business, make deliveries, obtain necessary industrial inputs, etc. Impacts to port and airport facilities would most likely be evaluated using benefit cost analysis methods specific to those modes.

Impact analysis will address significant secondary, or spinoff economic impacts of each design option from a city-wide and community standpoint. Secondary economic impacts could include a qualitative assessment, as well as the economic value (i.e., the monetized value) of impacts where the data permit such analysis. Values would be expressed as annual flows over an extended period (e.g., 50 years) and will be discounted to present value. Depending on the design option and the representative assets being studied, economic valuation of such loss impacts could include impacts on real property and housing values, loss of city tax base, relocation costs, household insurance and housing improvement costs, impacts on employment and local business impacts, and spinoff benefits such as enhanced waterfront amenities, improvements to water quality or natural habitats, or other environment-related spinoff benefits.

Adaptive capacity, the ability of the transportation facility and network to cope with the consequences of exposure, is another key component of vulnerability assessment and one that needs to be considered as part of the benefits calculation. An important concept when assessing adaptive capacity is the redundancy of the transportation network--the greater the network redundancies, the greater the ability of the transportation system to absorb the loss of use of a given facility affected by climate stressors (i.e. the higher it's adaptive capacity). On the highway network, redundancies may take the form of alternate routes which people can use to detour around facilities compromised by climate stressors. In some cases, the physical geography of a region presents many choke-points where network redundancy is limited. The ability to switch between modes could be an important aspect of redundancy in some areas.

The redundancy aspect of adaptive capacity can be analyzed by considering the daily cost of the additional travel time required by different types of facility users (e.g. drivers, bus and rail passengers, freight movements) when taking an alternative mode or detour route. This could be assessed with the aid of the regional travel demand model. By removing compromised links in the model, one can ascertain the optimal detour routes for travelers and the implications of those detoured trips on congestion. This will highlight routes that, if affected, might have significant ripple effects throughout the network (see discussion below). When performing the modeling work, care needs to be taken to ensure that none of the alternate routes or modes would also be compromised by climate stressors under the given scenario: in no case will a compromised route or mode be allowed to serve as a detour route. Once detour routes have been identified and the additional increment of travel time required to use them, the time-value of travel by different system users can be used to estimate the cost of losing use of a given facility. Facilities that are more heavily used and/or have longer detour routes (i.e. less redundancy) would tend to have lower

© ASCE 2014

adaptive capacity (and higher vulnerability). Note that the redundancy effort inherently incorporates the criticality of each facility into the vulnerability assessment.

Another component of adaptive capacity is how long it takes to restore service to the facility once it has been compromised: the longer the restoration time the lower the adaptive capacity and the higher is that facility's vulnerability. Restoration time (to be measured in days) can be considered a multiplier to the additional user costs associated with detours. In other words, each day of expected downtime can be multiplied by the user costs to arrive at a better representation of user costs if there is a failure. Restoration times might be as little as a day or two for temporary flooding where permanent damage is not expected or, as Hurricane Sandy showed, weeks for assets like tunnels and electronic rail infrastructure that require major restoration efforts. Assumed restoration times will be developed for different types of facilities based on previous experiences and close consultation with the asset owners. The estimates will also make use of the degree of exposure information so that a high level assessment of the degree of damage can be made (i.e. are only repairs needed or could full replacement be required?).

Replacement costs are the final component of adaptive capacity that should be considered in the vulnerability analysis. The costs to replace or repair a compromised asset are an important component of the adaptive capacity from an asset owner's perspective and, since Federal money is typically involved, of interest to the Federal government as well. Thus, all else being equal, larger transportation investments with higher replacement/repair costs can be considered to have a higher vulnerability worthy of greater prioritization for adaptive action. One can estimate high level replacement and repair costs for each facility based upon standard cost-estimating procedures, historical experiences, and consultation with asset owners. These repair and replacement costs would be added to the user costs discussed above to arrive at a vulnerability score (in dollars) for each facility under each climate scenario. In calculating the vulnerability scores, extra weight can be given to those assets affected in the recent extreme weather events to denote that these are proven risks. Extra weight can also be given to emergency evacuation routes if desired.

9. Consider practicality of each option, obstacles to implementation

Part of any engineering analysis is considering the practicality of implementing each option. In some cases, obstacles can be related to the technical details of the design itself such as the availability of materials and design footprint. In others, practicality relates to community acceptance and environmental impacts.

10. Make a final judgment based on sound scientific principles and peer acceptance

After all of the data gathering and analyses, and input from the stakeholders, the final decisions regarding the adaptation of an asset to the effects of extreme weather come down to the judgment of the planners, engineers, and stakeholders who can use their accumulated knowledge about what works and what does not. The large degree of uncertainty associated with climate models and the lack of data on which to base relative frequency decisions (based on statistics of past events) require that the results of the numerical and economic analyses be only one part of the decision-

© ASCE 2014

making process. These results must be synthesized with knowledge and judgment to reach a sound decision on how to proceed as discussed in Step 9 above. Technical information is there to inform the final decisions that must also include the realities of costs, political acceptance, sustainability, and the environment. This can be achieved by presenting the technical analyses in clear, easily understood language to agency decision makers.

APPLYING ASSESSMENT RESULTS TO STUDY AREA PRIORITIZATION

As noted in the opening section, transportation agencies are not likely to apply the engineering assessment process to all of the assets in a study area….it is too involved for facilities that are not considered vital to a region's mobility. However, one could use the vulnerability assessment to identify areas of a region that are particularly vulnerable to different environmental stressors. Critically vulnerable sub-areas that represent geographic locations within a study area could be defined where there are concentrations of highly vulnerable assets across the climate scenarios analyzed. Sub-areas could be defined in a way that provides a meaningful picture of vulnerability and allows for a comprehensive assessment of benefits and costs of adaptation alternatives within project budget and time parameters. Of particular concern in defining subareas is selecting locations containing transportation assets that serve particularly critical functions in the network, such as evacuation routes, redundant capacity, important freight flows (including debris removal after extreme events), or that serve important community access functions, such as access to hospitals or emergency centers. In addition, facilities that typically require pre-emptive closure during extreme weather events will be another factor when considering the definition of the critically vulnerable sub-areas.

The approach in this case would be to use the highly vulnerable sub-area designation to recommend that engineers take extra precaution when designing facilities in these areas. Such precaution might include using different input variables in engineering design calculations (such as drainage flows); considering higher design standards due to the higher risks associated with potential damage; incorporating mitigation strategies in the design themselves against higher than normal stresses; considering flexible design options that would make it easier to retrofit enhanced protection at some future date if deemed necessary; and incorporating advanced sensing and monitoring technologies into the design to monitor on a real-time basis the conditions that might cause asset failure.

CONCLUSIONS

Planning for climate adaptation can provide for the efficient use of resources in identifying critical system needs and developing and implementing the best solutions for adapting transportation infrastructure to the anticipated impacts. Transportation infrastructure is designed to "fit" into a local environment and to withstand a defined level of forces and climate impacts that have the potential to destabilize infrastructure integrity. The design criteria to which this infrastructure has been designed to meet is based upon historical climate data. However, as climate conditions continue to change, these criteria may no longer provide a sufficient level of protection or utilization.

© ASCE 2014

This paper has proposed a step-by-step process for considering adaptation considerations in facility/asset design, and an approach for establishing priorities. As noted, it is not likely that this process would be applied for all assets, but most likely reserved for those considered most important. Nonetheless, using this process for those assets considered critical would provide some sense of the sub-areas in a region where special design considerations might have to be made. Given recent experiences with extreme weather events, e.g. Superstorm Sandy, Hurricane Katrina, midwest floods, and wildfires in the U.S. west, transportation officials cannot ignore the mounting evidence that critical transportation infrastructure needs to be designed differently than what has been done in the past.

REFERENCES

Black, R. A., J. P. Bruce, and M. Egener. (2010). *Adapting to Climate Change—A Risk-Based Guide for Local Government,* Volume 1. Ottawa, National Resources Canada.

California Department of Transportation. (2011). *Guidance on Incorporating Sea-Level Rise for Use in the Planning and Development of Project Initiation Documents,* May 16. Sacramento, CA. http://www.dot.ca.gov/ser/downloads/sealevel/guide_incorp_slr.pdf.

California Natural Resources Agency. (2009). "Chapter 10, Transportation and Energy" in 2009 *California Climate Adaptation Strategy*. Sacramento, CA. http://resources.ca.gov/climate_adaptation/docs/Statewide_Adaptation_Strategy_-_Chapter_10_-_Transportation_and_Energy_Infrastructure.pdf

City of Toronto. (2011). *Beyond the Storm: A Risk-Based Process and Tool to Enable Better Understanding and Management of Environmental and Climate Risks*. Toronto, Canada. http://www.toronto.ca/teo/adaptation/action.htm

Commonwealth of Australia. (2006). *Climate Change Impacts and Risk Management: A Guide for Business and Government*. Canberra: Australian Greenhouse Office, Department of the Environment and Heritage.

Federal Highway Administration (FHWA). (2012). *Assessing Vulnerability and Risk of Climate Change Effects on Transportation Infrastructure: Pilot of the Conceptual Model*. Washington, D.C. Available from http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/vulnerability_assessment_pilots/conceptualmodel62410.cfm

FHWA, National Park Service, and U.S. Fish and Wildlife Service. (2011). *A Framework for Considering Climate Change in Transportation and Land Use Scenario Planning: Lessons Learned from an Interagency Pilot Project on Cape Cod,* Final Report. Cambridge, MA: Volpe National Transportation Center. July. http://www.volpe.dot.gov/coi/ppoa/publiclands/projects/docs/cape_cod_pilot_finalreport.pdf (accessed January29, 2013).

© ASCE 2014

Highways Agency and Parsons Brinckerhoff. (2008). *Climate Change Adaptation Strategy*. London: Highways Agency.

ICF International and Parsons Brinckerhoff. (2011). *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: The Gulf Coast Study, Phase II. Assessing Infrastructure for Criticality in Mobile, AL: Final Technical Memo Task 1*. Washington, D.C.: U.S. DOT Center for Climate Change and Environmental Forecasting.

Jacob, et al. (2011) LDEO/Civil Engineering, Columbia University; ClimAD, Chapter 9, page 311, Figure 9.11A. New York.

Kirshen, P., S. Merrill., P. Slovinsky, and N. Richardson. (2012). Simplified Method for Scenario-Based Risk Assessment Adaptation Planning in the Coastal Zone. *Climatic Change* 113:919—931

Maryland State Highway Administration and Maryland Transportation Authority. (2012). *Climate Change Adaptation Policy*. Annapolis, MD, February 1.

Metropolitan Transportation Commission (MTC), Caltrans, and Bay Conservation and Development. (2011). *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project*. Technical Report, Oakland, CA.

Meyer, M., M. Flood, J. Keller, J. Lennon, G. McVoy, C. Dorney, K. Leonard, R. Hyman, and J. Smith. (2014). *Strategic Issues Facing Transportation, Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report, NCHRP Report 750*, Transportation Research Board, Washington D.C.

Meyer, M. D., A. Choate, and E. Rowan. (2012). "Adapting Infrastructure to Extreme Weather Events: Best Practices and Key Challenges," Background Paper, AASHTO Workshop on Extreme Weather Events and Adaptation, May 20. Traverse City, MI: AASHTO.

Meyer, M. D., E. Rowan, M. Savonis, and A. Choate. (2012). "Integrating Extreme Weather Risk into Transportation Asset Management," Working Paper. Washington D.C.: AASHTO.

Meyer, M. and B. Weigel (2011), "Climate Change and Transportation Engineering: Preparing for a Sustainable Future," Journal of Transportation Engineering, Vol. 137, No. 6, pp. 393-403, American Society of Civil Engineers, June.

North Jersey Transportation Planning Authority (NJTPA). (2011). *Climate Change Vulnerability and Risk Assessment of New Jersey's Transportation Infrastructure*. http://www.njtpa.org/Plan/Element/Climate/documents/CCVR_REPORT_FINAL_4_2_12_ENTIRE.pdf.

Public Infrastructure Engineering Vulnerability Committee (PIEVC) and Engineers Canada. (2008). *Adapting to Climate Change—Canada's First National Engineering Vulnerability Assessment of Public Infrastructure*. Ottawa: Canadian Council of Professional Engineers.

© ASCE 2014

U.S. Army Corps of Engineers (USACE). (2011). "Sea-Level Change Considerations for Civil Works Programs," Circular No. 1165-2-212. Washington, D.C. http://planning.usace.army.mil/toolbox/library/ECs/EC11652212Nov2011.pdf

Vermont Agency of Transportation (VTrans). (2012). *Adapting Vermont's Transportation Infrastructure to the Future Impacts of Climate Change*. Montpelier, VT: VTrans Policy, Planning & Intermodal Development Division.

Virginia Department of Transportation. (2011). *Assessing Vulnerability and Risk of Climate Change Effects on Transportation Infrastructure: Hampton Roads Virginia Pilot*. Richmond.

Wall, T. and M. Meyer. (2013). "Risk-Based Adaptation Frameworks for Climate Change Planning in the Transportation Sector: A Synthesis of Practice." Paper 13-1418. TRB 92nd Annual Meeting Compendium of Papers (CD-ROM). Washington, D.C.: Transportation Research Board of the National Academies.

Washington State Department of Transportation (WSDOT). (2011). *Climate Impacts Vulnerability Assessment*. Olympia, WA.

WSDOT. (2012). *Guidance for Project-Level Greenhouse Gas and Climate Change Evaluations*. March. Olympia, WA: Environmental Services. http://www.wsdot.wa.gov/NR/rdonlyres/73ADB679-BDA6-4947-93CA87C157862DD7/0?/WSDOT_Project_GHG_Guidance_March_2012.pdf

.

© ASCE 2014

Evaluating Sustainability and Resilience in Infrastructure: Envision™, SANDAG, and the LOSSAN Rail Corridor

Richard Dial AICP LEED GA ENV SP[1], Bruce Smith P.E. FICE & MBA[2], and Gheorghe Rosca, Jr. P.E. MBA[3]

[1]10737 San Diego Mission Rd, #320, San Diego, CA 92108; PH (619) 952-0700; email: richarddial.sd@gmail.com (formerly with HDR)
[2]San Diego Association of Governments (SANDAG), 401 B Street, San Diego, CA 92101; PH (619) 699-1907; FAX (619) 699-1905; email: bruce.smith@sandag.org
[3]HDR, 2280 Market Street, Suite 100, Riverside, CA 92501; PH (951) 320-7319; FAX (951) 320-7301; email: gheorghe.rosca@hdrinc.com

Abstract
This paper documents the use of the Envision™ Sustainability Rating System, developed by the Institute for Sustainable Infrastructure in 2012, to evaluate the relative sustainability of two rail improvement projects in San Diego County, California undertaken by the San Diego Association of Governments (SANDAG). One project was at 100% design and the other at the 30% design level. SANDAG's intent in using this tool was to 'test drive' this new rating system and to provide a representative baseline on its overall sustainability efforts in designing and constructing projects on the San Diego County portion of the Los Angeles – San Diego – San Luis Obispo (LOSSAN) Rail Corridor. In addition, Envision could be used by future project development teams to take a more sustainable approach to project delivery. The methodology helped the project team to quantify measures that can be undertaken to further improve sustainable resilience, like increasing a project's lifespan, reduce overall life cycle costs, and to provide additional resilience against potential flooding from sea level rise and/or severe storm activity. One project earned Envision credits that would make it eligible for a Silver award, and the other remains to be evaluated. The evaluation process used can be instructive for use on other infrastructure projects.

Introduction/Overview

In planning and designing new or replacement infrastructure projects, project owners must wrestle with a number of challenges in their process, including:

- Competing for and obtaining sufficient funding to replace aging infrastructure
- Maximizing a project's design performance in an age of constrained resources, to get the highest possible value and longest design life given the available budget;
- The need to balance project goals with environmental and community desires; and
- Designing for potential risks and vulnerabilities such as more severe weather and sea level rise along coast lines and incorporating into their designs more resilience to overcome identified risks and vulnerabilities.

© ASCE 2014

The Envision Infrastructure Rating System offers a process by which these challenges can be potentially addressed and resolved, resulting in infrastructure projects that not only meet an owner's design specifications but can exceed them, as well as derive economic, social and environmental benefits as well. Such has been the experience in San Diego County, California, which we offer here as a representative case study on the use of Envision as an important project design and development tool.

SANDAG and the LOSSAN Rail Corridor

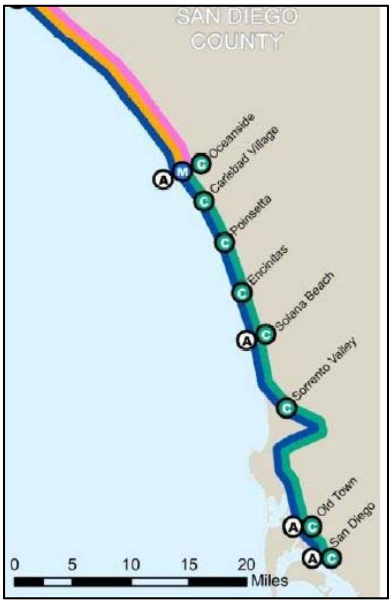


Figure 1: LOSSAN Corridor and rail stations within San Diego County. (Drawing credit: SANDAG)

SANDAG is providing $900 million toward the planning and construction of rail improvement projects on behalf of the two agencies – North County Transit District (NCTD) and Metropolitan Transit System (MTS) – that own the rail right-of-way as shown in **Figure 1**. The LOSSAN corridor parallels the coastline throughout the county, passing through six coastal cities and crosses six lagoons. The corridor is the second busiest intercity passenger rail line in the United States and the only viable freight rail link between San Diego and the rest of the nation. Built more than 100 years ago, the corridor is the second busiest intercity passenger rail line in the United States and it is used daily by as many as 70 trains, including NCTD's COASTER commuter train, Amtrak California's Pacific Surfliner intercity passenger rail service, Southern California Regional Rail Authority's Metrolink commuter rail service, and BNSF Railway freight trains.

To date, half of San Diego County's rail corridor is double tracked, with an additional 19 enhancement projects in design or under construction, toward a goal that eventually will see more than 97 percent of the corridor double tracked. Other infrastructure improvements include bridge and track replacements, new station platforms, pedestrian under crossings, and other safety and operational enhancements, part of a strategy to improve all modes of transportation within the congested Interstate 5 North Coast Corridor.

SANDAG staff are interested in implementing more sustainable practices in projects under development and needed a framework for measuring sustainability efforts. Following a presentation on Envision, they decided to test the new rating system to see how well it was suited to major linear infrastructure projects.

Sustainability, according to the U.S. Environmental Protection Agency, "creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations."[i] But how do you measure sustainability? Particularly in the coastal environment through which the rail corridor runs, with its many lagoons and threatened and endangered wildlife habitat, minimizing impacts and maximizing benefits of transportation infrastructure projects is an important consideration. Another

© ASCE 2014

design criterion about which SANDAG staff and design teams are mindful is the need to provide resilience to possible climate change and sea level rise through adaptable engineering strategies. Moreover, as responsible stewards of the financial resources it uses on the public's behalf, SANDAG's staff and project design teams seek to maximize project service life on the LOSSAN corridor and to get the best value for their investment.

This has led SANDAG to try Envision as a rating tool to assist in establishing a baseline for its current sustainability practices, and to identify new ways to increase sustainability on future projects.

The Sorrento Valley Double Track Project

SANDAG staff selected the Sorrento Valley Double Track (SVDT) Project, which was already at 100% design, as its initial Envision rating system test case. It will add a 1.1 mile section of new second mainline track north of the existing station located at 11170 Sorrento Valley Road, San Diego, CA 92121, as shown in **Figure 2**. In addition to this new track, other project elements include raising portions of the existing track bed by up to five feet to put the rails above the 50-year flood level. Two 1940's-era timber bridges will be replaced with concrete structures. Retaining walls will be built adjacent to the tracks near the station's parking lots, which 81 spaces added for a new total of 189.

Figure 2: The Sorrento Valley Rail Station and the SDVT Project Area. The project parallels Los Peñasquitos Creek, from I-5 to the lagoon. (Photo credit: SANDAG)

An embankment protection system will be installed along the west side of the tracks, adjacent to Los Peñasquitos Creek, and a new drainage channel will be constructed along the eastern side of the tracks to improve drainage.

The budget for the project is $33.7 million, paid for through federal, state and local sources, including; Federal Section 5307, California State Proposition 1B and local *TransNet*, the half-cent sales tax for transportation approved by San Diego County voters. The project started construction in January 2014 and is planned to be completed in mid-2015.

Need for the SVDT Project

SVDT was ranked as a near-term priority project by the LOSSAN Prioritization Analysis in 2009 and is required to meet the projected 2015 service levels for passenger trains.

Flooding due to rain storms can adversely affect passenger and freight rail service up and down the entire LOSSAN corridor. The Penasquitos creek bridge crossing and half a mile of track to the North within the project area is current subject to closure

© ASCE 2014

during 10-year storm events. During a 2010 winter storm, sections of track embankment washed away, as shown in **Figure 3**.

Figure 3: Bridge 248.7 over Las Penasquitos Creek, December 2010 (Photo credit: NCTD MOW)

The raised track bed and embankment will protect this section of track from the higher water levels of a 50-year storm event, reducing the potential disruption to rail services.

Adding this second mainline section will facilitate the passing of passenger and freight trains north of the Sorrento Valley Station, an area with the second-longest stretch of single track San Diego County, which will help improve reliability and on-time performance of rail services.

About the Envision Sustainability Rating System (Envision)

Envision is the result of an effort to develop a broadly applicable, standardized sustainability rating system, undertaken by three major American professional associations: the American Council of Engineering Companies (ACEC), American Public Works Association (APWA), and the American Society of Civil Engineers (ASCE), who jointly founded the Institute for Sustainable Infrastructure (ISI). ISI partnered with the Zofnass Program for Sustainable Infrastructure at Harvard University's Graduate School of Design, and the result of this collaboration is the Envision system. Tim Psomas, ISI's founding Chairman is quoted as saying that "Envision was developed by taking the best of about 900 infrastructure rating systems from the U.S. and around the world".[ii]

Envision can rate a wide variety of horizontal infrastructure projects, as seen in **Figure 4**.

© ASCE 2014

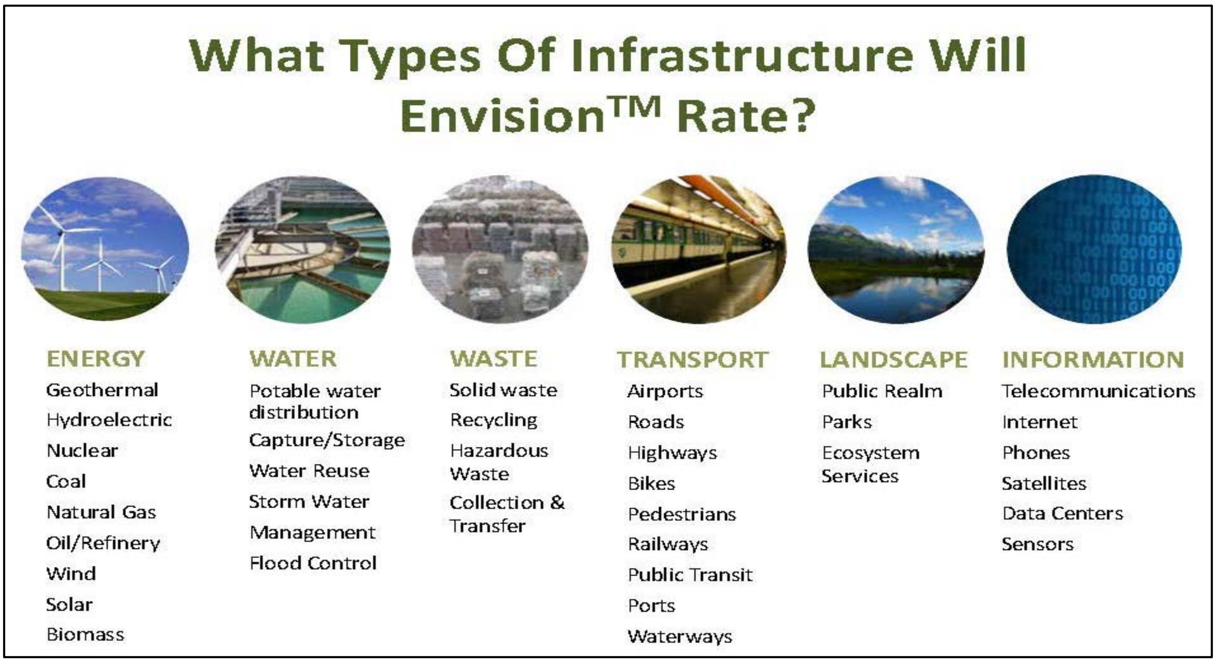


Figure 4: Types of Infrastructure Projects Applicable to Envision (Source: ISI)

Scoring Categories

Envision's scoring system consists of 60 credits grouped under within five categories**:**

1. Quality of Life; which considers a project's purpose, community, and well-being;

2. Leadership; which includes the use of collaboration, and integrated project management and planning;

3. Resource Allocation; which includes materials, energy needs, and water requirements;

4. Natural World; which includes and the project's impacts such as siting, land and water and consideration of biodiversity; and

5. Climate and Risk; which addresses greenhouse gas emissions, the potential for extreme weather events, and the need to mitigate against those factors through incorporating resilience into projects.

Levels of Achievement

Envision credits are based on industry best practices, and each credit can have up to five levels of achievement, which are non-linear, ranging from *Improved* "performance that is at or above existing conventional standards of practice" all the way to *Restorative*, which goes beyond no net impact to "restore natural or social systems." :

© ASCE 2014

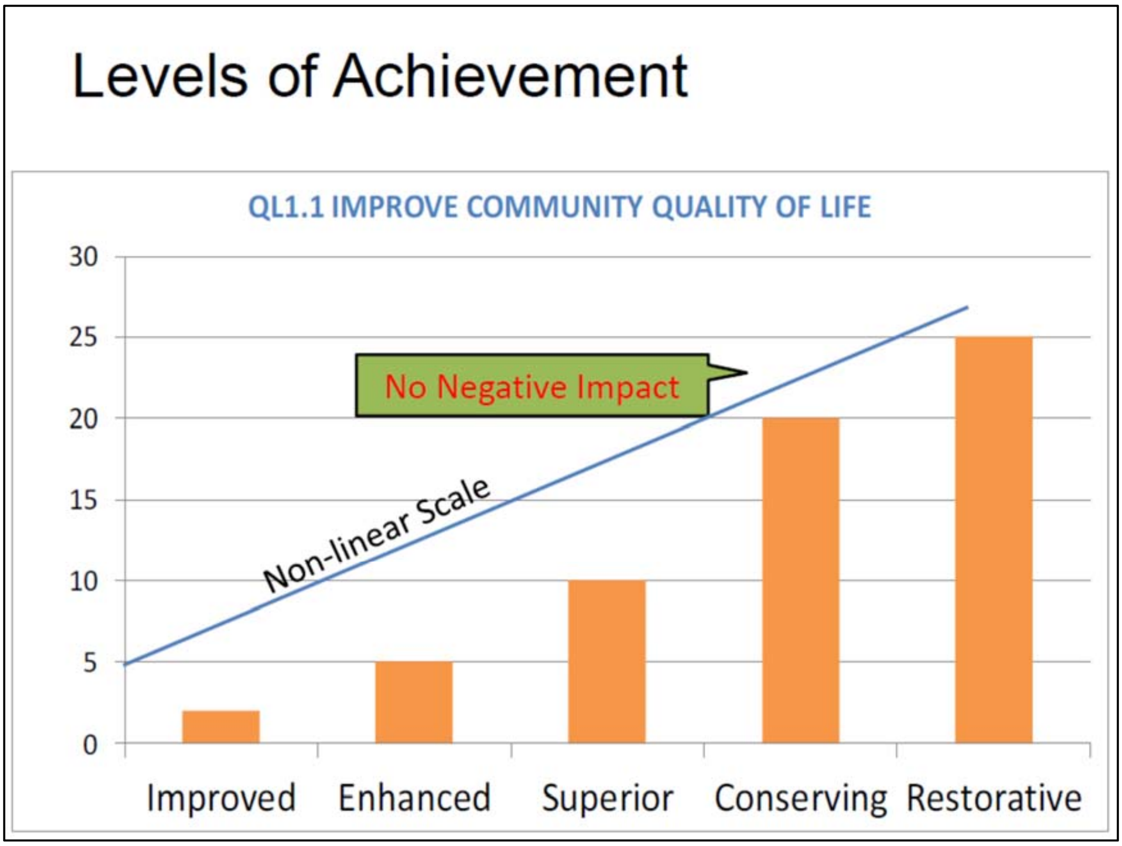


Figure 5: Envision Credit Points by Level of Achievement (Source: ISI)

Figure 5 provides a representative view of how the points vary by level, such as here with Credit Quality of Life 1.1 (Improve Community Quality of Life).

Envision Scoring Process and Results for SVDT Project

There are a total of 847 points possible with Envision. Envision award levels are determined by calculating the total points earned and dividing into the total points applicable to a project.

If any credit is not applicable to the project, its points are not taken into consideration when calculating the percentage of total points earned against available points. In other cases, when a credit is applicable but there is no project performance that rises to the minimum of "improved" achievement, then that credit is marked "No Value Added", with a score of zero points toward the possible number for that credit.

Envision also includes in each category an Innovate or Exceed Credit Requirements credit. These credits represent outstanding performance that can be applied to other projects, and are only available through ISI's third-party verification process. For more information on Envision, its credits and credit categories, and scoring, visit www.sustainableinfrastructure.org.

For the SVDT project, Richard Dial, an Envision Sustainability Professional, met jointly with Bruce Smith, SANDAG's project manager and Gheorghe Rosca, Jr., HDR's rail project manager to gather background information and to conduct a preliminary review of the available credits possible in the five Envision categories.

© ASCE 2014

Following that initial meeting, an online Envision workbook for the project was established on ISI's website, and the project was scored to determine its potential rating level. The Sorrento Valley Double Track project earned a total of 221 points out of 713 points applicable, equaling 31 percent of the available points. The scoring results of that assessment are presented in **Table 1**.

Table 1: Summary of Total Points Earned for SDVT Using Envision

Credit Category	Applicable Points	Total Points Pursued	Percentage of Available Points
Quality of Life	149	51	34%
Leadership	106	42	40%
Resource Allocation	171	32	19%
Natural World	165	49	30%
Climate and Risk	122	47	39%
Total Workbook Points	**713**	**221**	**31%**

Source: HDR/ISI

While SANDAG has not submitted the SDVT project for verification and an award, its scoring of 31% would make it potentially eligible after verification for a Silver Award. Envision award levels and the respective percentages of points required for each level are shown in **Figure 6**. SANDAG's senior staff were not ready to invest in formal verification at this date until the benefits of the Envision system could be more clearly documented, and preferred to use their available resources at this time for assessment and training of its staff.

Given page constraints, here are highlights from the overall category/credits from the SVDT assessment:

Recognition Level	Minimum Applicable Points
Bronze Award	20%
Silver Award	30%
Gold Award	40%
Platinum Award	50%

Figure 6: Envision Minimum Applicable Points per Award Level (Source: ISI)

QL 1.1 Improve community quality of life – Project provides for increased train frequencies, which will enhance alternative commute options and associated congestion.

QL 2.2 Minimize noise and vibration – Project worked with local businesses to identify issues, and limited their use of vibratory compactors to reduce impacts.

QL 2.3 Minimize light pollution – Project incorporated Dark Sky requirements to protect nearby Palomar Observatory.

LD 1.1 Provide effective leadership and commitment - Effective Leadership exists through regionally-approved guiding documents like the Regional Transportation Plan & LOSSAN Corridor Project Prioritization Analysis.

LD 1.2 Sustainable Management System – A Climate Action Strategy for the San Diego region was adopted by the SANDAG Board in 2010.

© ASCE 2014

LD 1.3 Foster collaboration and teamwork – Project fostered collaboration by working closely with the Penasquitos Lagoon Foundation and California State Parks in selecting an environmental mitigation site.

LD 1.4 Provide for stakeholder involvement – SANDAG has an active and engaged program of involving all stakeholders, including for this project stakeholder involvement and project mitigation being done in the adjacent Torrey Pines State Park.

LD 2.1 Pursue By-Product Synergy Opportunities – Project team found by-product synergy through the use of fly ash in concrete (Also provides credit in RA 1.1)

LD 3.2 Address conflicting regulations and policies – Project team addressed conflicting regulations; lagoon restoration vs. mitigating specific impacts, adjusted planting plans to satisfy the request of the Penasquitos Lagoon Foundation and California State Parks through a collaborative process.

LD 3.3 Extend useful life - Project's design yields concrete bridges with a service life of 100 years (25 years more than the state Department of Transportation's design standard!).

RA 1.5 Divert waste from landfills – reuse of soil removed from an adjoining project

RA 1.6 Reduce excavated materials – reuse of surplus dirt from adjoining project

NW 1.1 Preserved habitat on west side of project (through Alternatives Analysis)

NW 1.2 Protect wetlands and surface water - Preserves wetlands west of tracks

NW 2.2 Reduce pesticide and fertilizer impacts – Accomplished through the use of native plants

NW 3.3 Restore disturbed soils – State Park Mitigation

CR 2.1 Assess climate threat – SANDAG completed a Sea Level Rise Study to better determine actual vs. forecast changes

CR 2.3 Prepare for long-term adaptability – pile joints allow for additional sections in the event of sea level rise

CR 2.4 Prepare for short term hazards – Project designed to accommodate 50 year storms, not just 100 year events

One key element of the project's design worthy of mention addresses how the project will extend the service life of the concrete structures from 75 to 100 years using fly ash or corrosion inhibitors. The use of fly ash not only is an example of looking for opportunities for by-product reuse synergies, but it also created a structure with a 100-year lifespan, a significant increase over the existing Caltrans guideline for a 75-year project lifespan for bridges, creating a substantial lifecycle cost savings for SANDAG and the taxpayers of the region.

This portion of the project's assessment was by Tourney Consulting Group, a specialist sub consultant, using the STADIUM service life modeling techniques.

© ASCE 2014

The graphs below in **Figure 7** indicate how much cover and fly ash and or corrosion inhibitors are required to extend the design life up to 100 years, for concrete made with type 2/5 cement and exposed to moderate chloride exposure in coastal valleys in San Diego County.

Note that these results are site specific and that exposure conditions and climatic conditions are also drivers of chloride diffusion and they only apply to projects at this location with similar exposure.

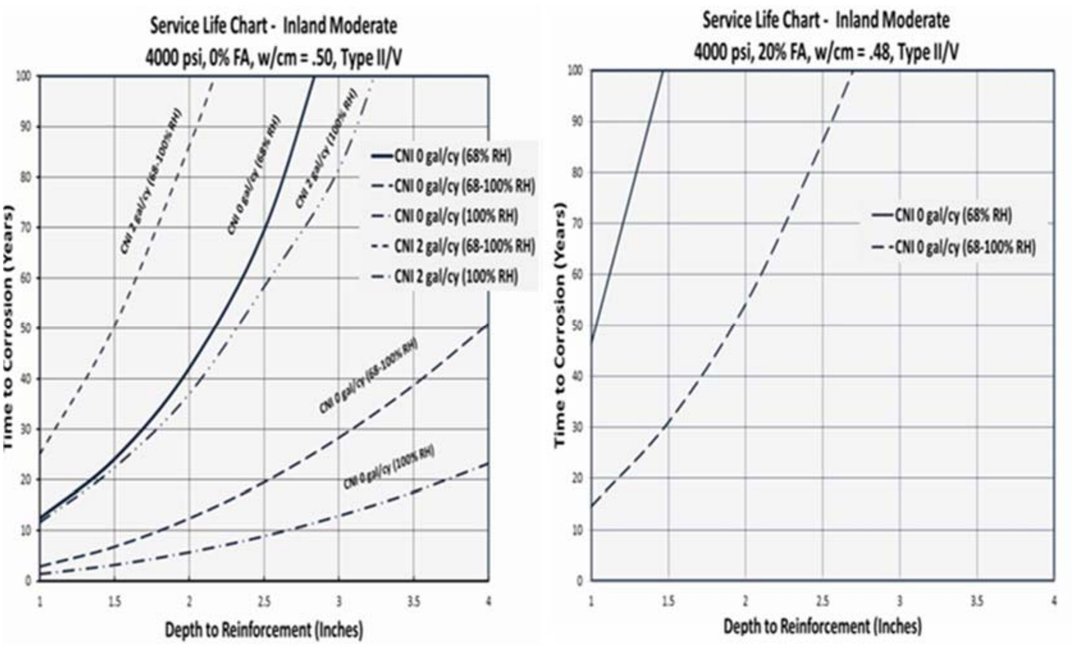


Figure 7: Extended Service Life through additional Fly Ash in Concrete Mix

Source: SANDAG

The San Elijo Double Track and Bridge Replacement Project

The second project on which SANDAG will be using the Envision rating system is the San Elijo Double Track and Bridge Replacement Project (SELDT). Because SELDT is only at the 30% design level, this creates an opportunity to incorporate the results of the Envision assessment from the earlier SVDT project. Opportunities to further increase the sustainability and resilience of this project beyond the level achieved for SVDT will be explored through the best practices suggested through the Envision planning process while the project's design development can still be modified.

Figure 8: The San Elijo Double Track and Bridge Replacement Project, with the project area identified in yellow. (Drawing credit: SANDAG)

© ASCE 2014

SELDT would add 1.5 miles of second main track and would replace an aging timber rail bridge between the cities of Encinitas and Solana Beach, as seen in **Figure 8**. It would also incorporate pedestrian and bicyclist improvements, as well as would install foundational work at the project's affected at-grade vehicle crossing so as to allow the City of Encinitas to apply for a Quiet Zone designation from the Federal Railroad Administration, should it choose to do so in the future.

This project is consistent with SANDAG's goal to increase rail capacity to allow for future demand for more train frequencies and to provide operational flexibility and reliability, as well as to provide a more robust regional travel alternative. It would include signal and grade-crossing modifications at Chesterfield Drive in the Cardiff area, a new retaining wall north of the San Elijo Lagoon, and track and signal improvements near the Solana Beach train station.

It is also compatible with an extension of the Coastal Rail Trail, a 44-mile long system of planned non-motorized transportation facilities for pedestrians and bicyclists. As mentioned, the project would also impact restoration efforts for the San Elijo Lagoon, through which the LOSSAN rail corridor passes.

As this project is still in the environmental clearance and design phase, the Envision process offers many chances to increase use of its five major categories to enhance the project for its users and beneficiaries, as well as to be good stewards of the public resources being used to develop and construct this project.

As a starting point in the process, a meeting was held where the ENV SP Sustainability Lead met with the Project Manager and the other technical task leaders. Each Envision credit was reviewed and discussed by the team, and both achievable and "stretch" target achievement goals were set. This information was entered into a workbook on the www.sustainableinfrastructure.org website, along with project team notes. As the San Elijo project's design process is advanced, the team will continue to receive questions and feedback from the Sustainability Lead, who will also collect and document the information necessary to support a potential submittal for verification. Verification is not a necessary component of the Envision process, but as mentioned earlier, can be useful in reporting compliance with environmental agreements and to showcase an organization's commitment toward the use of sustainability practices to achieve a higher level of performance than might be possible without the best practices and processes contained through the Envision rating system.

Updated results of this SELDT effort will be shared with conference attendees in November 2014.

Both the SVDT and the San Elijo projects are rail components of a much larger program of projects to increase capacity and improve operations on along San Diego's coastal transportation corridor. This program incorporates a very active, cooperative effort involving representatives from SANDAG, the California Department of Transportation (Caltrans), the coastal cities impacted by the projects, California Coastal Commission, State and Federal resource agencies, environmental organizations such as the lagoon conservancies, transportation advocacy groups, and the general public.

© ASCE 2014

Opportunities to better design and integrate these projects into the built environments in which they are located is seen as a key element of future project planning, and SANDAG's use of Envision as a planning and design tool is likely to continue beyond the two projects involved in this pilot effort.

Other elements of this sustainability work may include assisting SANDAG project managers and staff in getting trained and prepared to take the Envision Sustainability Professional examination, which would further inculcate and stimulate its use as a standard design practice for infrastructure projects of all types and sizes.

Conclusion

Advancing the use of sustainable practices and materials through a broad-based, collaborative process such as the Envision rating system can address and help resolve the three challenges project owners frequently face in the planning and design of their infrastructure projects. As shown in this representative case study, Envision can be used at any stage in the design process to document and benchmark an entity's existing sustainability practices. Used earlier in the design process, Envision review can result in projects that offer:

- Longer project lifespans and higher performance (thus saving time and money, and getting the best value for the available budget);
- An inclusive, iterative process that suggests the active involvement of a wide range of stakeholders and those impacted by a project, both from a technical and non-technical perspective, yielding opportunities to incorporate better design techniques and a higher integration within the community/environment where the project is located; and
- An ability to assess potential risks and vulnerabilities through the design process, allowing for creative solutions to address them.

As knowledge about the many benefits of the Envision rating system becomes better known throughout the engineering community, among governmental entities, and among the general public, its utility will be increasingly seen and appreciated. The Envision rating system provides a great framework for transportation professionals to improve the sustainability of their efforts.

---

[i] http://www.epa.gov/sustainability/basicinfo.htm

[ii] Neimeyer, T. (2011) Envisioning an Infrastructure Sustainability Rating System. *Progressive Engineering*, September 2011. Retrieved from http://www.cenews.com/article/8462/envisioning_an_infrastructure_sustainability_rating_system

LOSSAN Corridor Project Prioritization Analysis by Cambridge Systems, Inc. July 2009

Service Life Design Report for the Sorrento Valley Double Track Project, TCG February 2014.

San Diego Region Coastal Sea Level Rise Report, M&N and Everest, September 2013.

© ASCE 2014

Climate Change Vulnerabilities and Risk Based Management Approaches Used on Transportation Assets

Arthur H. Hirsch[1] and Benjamin E. Kunstman[2]

[1]TerraLogic Sustainable Solutions, 5766 Flagstaff Road, Boulder, Colorado 80302; PH (303) 786-9111; email: AHirsch@TerraLogicss.com
[2]Environmental Engineer (Graduate of University of Colorado-Boulder), 640 Ithaca Drive., Boulder, Colorado 80305; PH (303) 518-4776; email: benjamin.kunstman@gmail.com

ABSTRACT

Climate change is being recognized as a threat to transportation infrastructure and systems. The climate change impacts upon transportation systems will be felt short term via episodic-extreme weather events and long term climatic changes resulting from increased temperatures. These climate change impacts to transportation infrastructure have the potential of causing significant disruption in the movement of goods and services and impacting the overall quality of life to many residents and communities.

This paper provides an overview of climate change risk management approaches for transportation systems with a national and international perspective. A literature review was conducted to identify climate change risk management approaches used in the United States, Europe and New Zealand. Vulnerability analysis strategies, risk management approaches and climate change adaptation plans for these countries were identified reviewed and compared. Similar risk management approaches were identified between countries with differing governmental requirements and regulations. There are a limited number of countries worldwide that have developed risk based transportation programs to adapt to climate change.

INTRODUCTION

Climate change is defined as a statistically significant variation in either the mean state of the climate or its variability over an extended period, typically decades or longer, that can be attributed to either natural causes or human activity (IPCC, 2007). The concept of climate change attributable to anthropogenic greenhouse gas emissions has been recognized and accepted by the vast majority of climate scientists

© ASCE 2014

world-wide. The average temperature of the earth is 15° C and predictive models have estimated that this average temperature may increase 3-5° C by the end of the 21st century (NRC, 2008).

The specific location, impacts and magnitude of climate change at a local or regional scale is not possible to predict at this time; however, scientists have identified 5 climate change impacts that will affect the US transportation system (NRC, 2008):

- Increases in extreme temperature days and heat waves
- Increase in Arctic temperatures
- Rising sea levels
- Increases in intense precipitation events
- Increase in hurricane intensity

Transportation systems are at some risk due to climate change related to extreme weather events within the United States (US) and worldwide. In the long term, climate change impacts have a probability of impacting the levels of service, safety and the integrity of the transportation system infrastructure for both coastal and non-coastal states. Existing highway system design criteria and highway assets that were developed based upon past climate patterns and statistical data have a reasonable potential of being or becoming outdated and ineffective. Lack of adaptation under a climate change context could lead to structural failure, environmental damage, risk to the traveling public and impacts to local communities and quality of life.

This paper identifies the climate change risk management strategies and approaches that are being used in the US and internationally to address climate change impacts and adaptation. Based upon the literature search performed in this study, there are a limited number of countries that have developed risk-based transportation programs to adapt to climate change. Climate change risk management policies and approaches for the US, Europe (UK) and New Zealand transportation agencies and governments are summarized.

Climate change risk management approaches which were investigated in this study include projects and programs that assess the impacts, vulnerability, or risk associated with climate change to assets of roadway infrastructure. Assets such as roadways, bridges, drainage systems and utilities are potential risk areas within transportation corridors.

Some of the reviewed risk management programs also included adaptation assessments, which identify and compare options to reduce the vulnerability of transportation systems against actual or expected climate change effects.

To classify and discuss risk based climate change programs consistent definitions are used throughout this report:

- Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes (IPCC, 2007).

© ASCE 2014

- Risk is the combination of two elements: (1) the likelihood of an event occurring (e.g., flooding, hurricane, heat wave, etc.) and (2) the consequence of such an event (e.g., moderate highway flooding resulting in disruption in services for several days) (NZCCO, 2004).
- Exposure is the nature and degree to which a system is exposed to significant climatic variation (IPCC, 2007).
- Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change (IPCC, 2007).
- Adaptation assessment is the practice of identifying options to adapt to climate change and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency and feasibility (IPCC, 2007).

Climate change risk management approaches exist in different scales at the national, state or county/city level. The purpose of the literature review is to provide a comprehensive summary of risk management efforts at a national level; however, smaller scale risk based programs are also identified.

CLIMATE CHANGE RISK MANAGEMENT- UNITED STATES (US)

In 2007, the Intergovernmental Panel for Climate Change (IPCC) published their Fourth Assessment Report summarizing their Working Group reports. In addition to confirming that climate change is occurring now, the report elaborated on impacts of climate change and adaptation strategies to reduce vulnerability (IPCC, 2007). In response, the National Research Council (NRC) issued a report in 2008, focusing specifically on the consequences of climate change for the infrastructure and operations of United States (US) transportation systems (NRC 2008). This NRC study was requested by the Transportation Research Board (TRB), and alerted US transportation decision makers to key concerns facing the transportation system.

Concern about climate change and adaptation was voiced by former Secretary of the Department of Transportation Ray LaHood in his Policy Statement on Climate Change Adaptation in June, 2011. This policy statement was based on Executive Order 13514, requiring that all Federal Agencies develop and implement climate adaptation plans. Secretary LaHood stated that:

> *"The United States Department of Transportation (DOT) shall integrate consideration of climate change impacts and adaptation into the planning, operations, policies, and programs of DOT in order to ensure that taxpayer resources are invested wisely and that transportation infrastructure, services and operations remain effective in current and future climate conditions. The climate is changing and the transportation sector needs to prepare for its impacts"* (LaHood, 2011).

The Federal Highway Administration (FHWA), an agency within the US Department of Transportation (DOT), began to look at climate change risk management with several case studies in 2008. The initial FHWA studies included vulnerability

© ASCE 2014

assessments for the Gulf Coast and Atlantic Coast when considering projected sea level rise. While finding that key transportation infrastructure was threatened by climate change, the studies also acknowledged that the climate projections needed to be at a finer scale to develop effective strategies on a specific project level (FHWA 2014).

In order to respond to climate change and the need for adaptation, FHWA developed a conceptual risk/vulnerability model used in pilot studies in 2010. The goal of the conceptual model is to support transportation decision makers responsible for planning and asset management in the identification of assets that are vulnerable to climate change related threats. The model consists of the following primary components elements:

- inventory assets,
- gather climate information
- vulnerability analysis
- identify, analyze and prioritize adaptation options
- identify resources that should be monitored

This FHWA framework included vulnerability and risk assessments for transportation infrastructure, and was piloted at five locations in 2010 and 2011, New Jersey, Oahu, California (San Francisco), Virginia and Washington (FHWA 2012).

Using the feedback from the DOT pilot studies, the FWHA revised the conceptual model, and released the "Climate Change & Extreme Weather Vulnerability Assessment Framework" in 2012. The goal of the conceptual climate change risk model was to assist transportation decision makers in identifying assets that are the most vulnerable to climate change related impacts and threats. This updated framework is being used across the US, including 23 state DOTs and 28 Municipal Planning Organizations (MPOs) that have assessed or are assessing their vulnerability to climate change to date (FHWA, 2014). The model (Figure 1) consists of three primary elements that follow a basic risk management approach (FHWA, 2012):

1. Define Scope
    - Identify Key Climate Variables
    - Articulate Objectives
    - Select & Characterize Relevant Assets
2. Assess Vulnerability
    - Collect & Integrate Data on Assets
    - Develop Climate Inputs
    - Develop Information on Asset Sensitivity to Climate
    - Incorporate Likelihood & Risk (Optional)
    - Identify & Rate Vulnerabilities
    - Assess Asset Criticality (Optional)
3. Integrate Into Decision Making

© ASCE 2014

- Incorporate into Asset Management
- Integrate Into Emergency & Risk Management
- Contribute to Long Range Transportation Plan
- Assist in Project Prioritization
- Identify Opportunities for Improving Data Collection, Operations or Designs
- Build Public Support for Adaptation Investment
- Educate & Engage Staff & Decision Makers

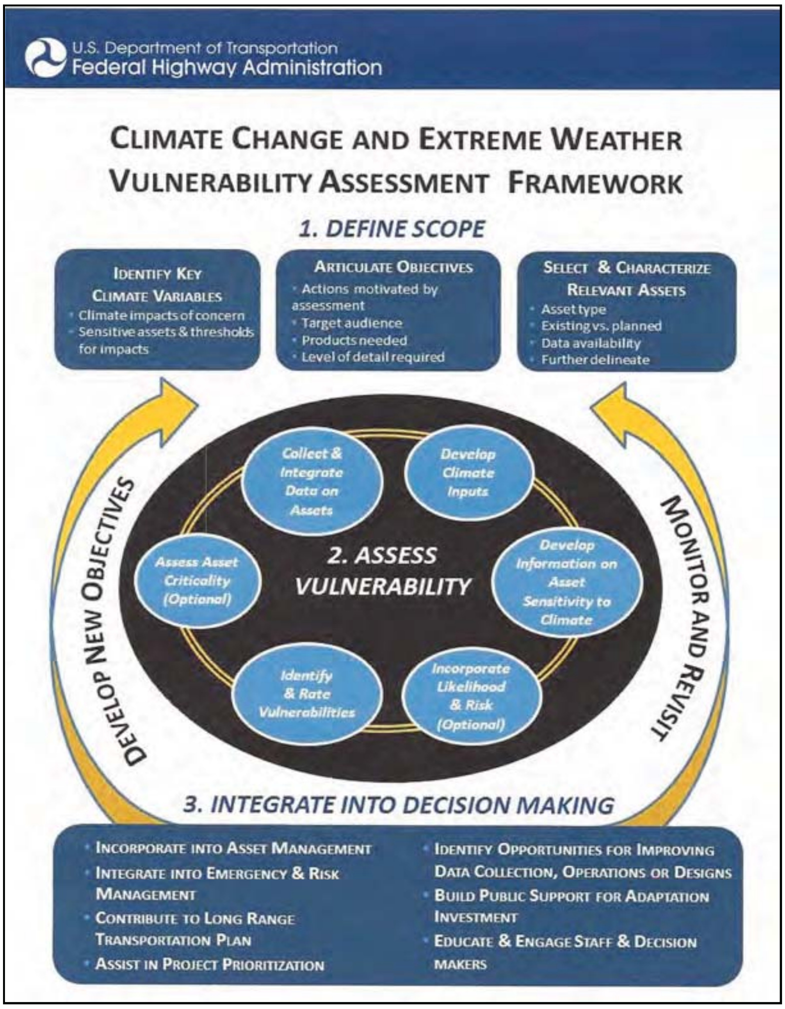


Figure 1: Climate change and extreme weather vulnerability assessment framework

The framework utilizes scenarios from more than twenty major global climate models to develop projected climate input scenarios (FHWA, 2012). This predictive modeling approach reduces bias from model outputs, and results in a range of climate inputs rather than a single climate scenario. The FHWA framework includes an optional risk assessment, integrating the severity of an impact with the likelihood that an asset will experience this impact. The risk assessment approach was included in the San Francisco, California and Oahu, Hawaii pilot programs. The assessment

© ASCE 2014

framework does not explicitly include an adaptation plan; however, an "Engineering Strategic Initiative Adaptation Study," funded for three projects in 2014, will develop recommended engineering solutions to adapt to climate vulnerabilities identified by the vulnerability assessment framework (FHWA, 2014).

CLIMATE CHANGE RISK MANAGEMENT -EUROPE

European Union. Members of the European Union (EU) have been developing risk management strategies to adapt to climate change over the past several years. In 2009, the European Commission (EC) issued the white paper entitled "Adapting to Climate Change: Towards a European Framework for Action". The objectives of the adaptation framework focused on four areas of action (EC, 2009):

1. Building a solid knowledge base on the impact and consequences of climate change for the EU
2. Integrating adaptation into EU key policy areas
3. Employing a combination of policy instruments to ensure effective delivery of adaptation
4. Stepping up international cooperation on adaptation

This white paper represented Phase 1 of the EU's multi-phase approach toward an adaptation strategy. Phase 2 of the EU adaptation strategy began in April, 2013, with the EC issuing a proposal for an EU Adaptation Strategy. In Phase 2, the EC took a proactive stance that "by prioritizing coherent, flexible and participatory approaches, it is cheaper to take early, planned adaptation action than to pay the price of not adapting" (EC, 2013). The objectives of the EU Phase 2 Adaptation Strategy include:

Promoting action by Member States

- Encourage all Member States to adopt comprehensive adaptation strategies
- Provide funding to support capacity building and step up adaptation action in Europe
- Introduce adaptation at a location level (Covenant of Mayors framework)

Better informed decision-making

- Bridge the knowledge gap in climate impacts and adaptation
- Further develop the Climate-ADAPT model as the main adaptation reference and database for climate change information in Europe

Climate-proofing EU action:

- Promote adaptation in key vulnerable sectors
- Facilitate climate-proofing of the Common Agricultural Policy, the Cohesion Policy and the Common Fisheries Policy
- Ensuring more resilient infrastructure
- Promote insurance and other financial products for resilient investment and business decisions

The European Environment Agency (EEA) has made an effort to close informational and knowledge gaps among member nations, preparing multiple reports focusing on

© ASCE 2014

transport infrastructure. Within the past two years, the EEA has provided an initial assessment for the transport sector (EEA, 2012), provided policymakers with information to support adaptation planning and implementation (EEA, 2013a), and has prepared a technical paper establishing a map of current actions in EU countries for adapting the transport system to climate change (EEA, 2013b).

The 2013 EEA technical paper included results from a questionnaire issued to EEA members and cooperating countries. This questionnaire aimed to produce a "comprehensive overview of the state of transport adaptation actions and climate change in EEA countries, as conducted by governments and by infrastructure managers" (EEA, 2013b). The study found that sixteen EEA member countries have developed a national adaptation strategy, with the transport sector being specifically addressed in strategies from Austria, Denmark, Finland, France, Germany, Ireland, Lithuania and the United Kingdom (UK). Transport adaptation strategies are addressed in less detail in some additional countries' adaptation strategies, including Malta, the Netherlands Romania, Spain and Switzerland.

The questionnaire found that the only transport authorities who have prepared adaptation strategies are Denmark, Finland and the UK. Rather than being a section of a national action plan, the inclusion of climate change adaptation strategies by transport authorities results in conscientious transport planning and decision-making. The UK's British Department for Transport's (DfT) climate change risk management approaches have been outlined below, as their strategy and framework is the most clearly and thoroughly documented.

United Kingdom (UK). In response to the IPCC 4th Assessment Report, the UK introduced the Climate Change Act 2008. This act established assessments of the UK's ability to meet risks and opportunities brought about by climate change. The Local Transport Act 2008 dictated that local transport authorities would need to consider the government's adaptation policies and guidance in their Local Transport Plans (LTPs). Local authorities are required to report their progress on adapting to climate change, and as of 2009, 56 local areas had agreed to improvement targets in their Local Area Agreements for climate change adaptation (Transport Planning Society, 2009). The Transport Planning Society's "Local Transport: Adapting to Climate Change" provides local authorities in the UK with technical resources and approaches for evaluating vulnerabilities and strengthening resilience.

In 2009, the Highways Agency of the British DfT developed the "Highways Agency Climate Change Adaptation Strategy and Framework" (Highways Agency, 2009). This document lays out the Highways Agency's commitment to assess the risks climatic changes pose to the UK road network, and to develop solutions to remove or reduce these risks. The Highways Agency Adaptation Framework Model (HAAFM) was developed to accomplish these goals by addressing transport system vulnerabilities. The HAAFM is a cyclical systematic process that is composed of seven stages as shown in Figure 2:

© ASCE 2014

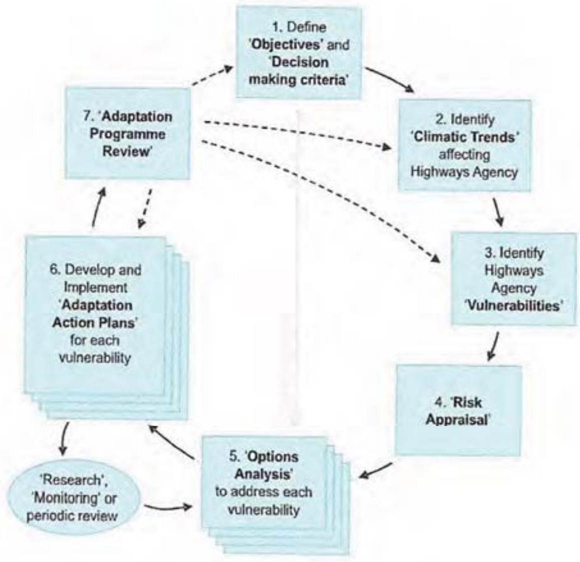


Figure 2. Highways Agency adaptation framework model

The HAAFM uses the latest climate modeling projections from the UK Climate Impacts Program (UKCIP). HAAFM also utilizes a risk assessment approach in order to prioritized vulnerabilities. Criteria used to assess transport vulnerabilities include uncertainty, extent of disruption, severity of disruption, and the relative rate of climate change to asset expected life. The development of climate adaptation action plans follows a four-step framework:

1. Identify feasible options
2. Determine expected outcomes
3. Estimate costs and benefits
4. Determine preferred option

After a climate change adaptation action plan is developed and implemented for each selected vulnerability, the actions are further researched, monitored, and put under periodic review to evaluate the effectiveness of the solution.

New Zealand and Australia Risk Management Approaches. New Zealand and Australia have also been active in climate change risk management for transportation assets. In New Zealand, the government responded to the IPCC Third Assessment report in 2001, and began to form policies that would account for and adapt to climate change. Local governments in New Zealand are responsible for identifying and managing transportation assets that are vulnerable to climate change effects.

The New Zealand Ministry for the Environment published a guidance manual identifying and assessing potential effects and impacts of climate change for local governments' reference. The initial guidance report was published in 2004, with an updated edition in 2008 after the IPCC Fourth Assessment report was released. The

© ASCE 2014

updated guidance manual contains a risk assessment procedure for local authorities to follow based on the New Zealand Standard for Risk Management. The standard risk assessment process is shown in Figure 3 (Ministry for the Environment, 2008):

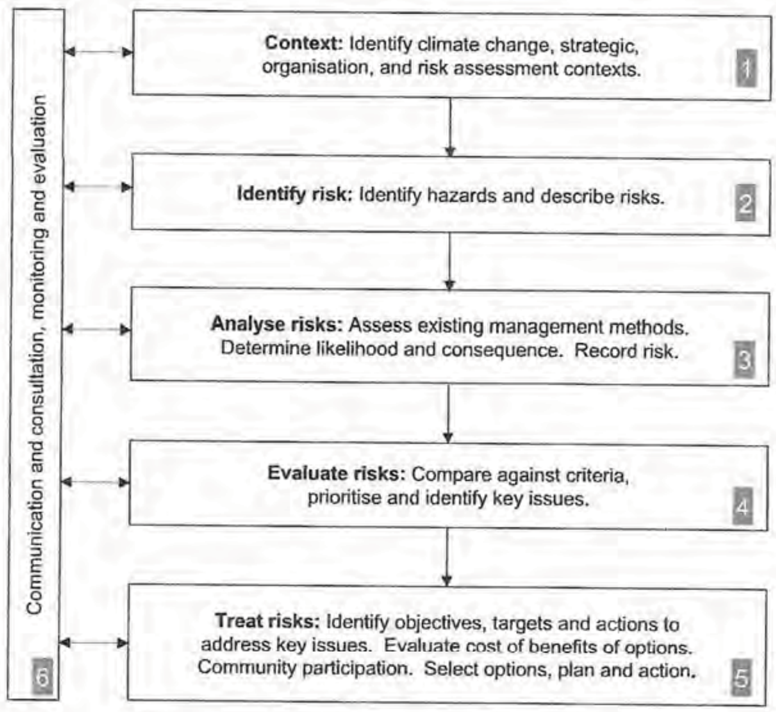


Figure 3. New Zealand climate change risk assessment process

A report commissioned by the New Zealand Transport Agency applied these risk management techniques to assess both coastal and inland road networks and infrastructure. The project was able to define priority adaptation responses for each profile, and provided feedback for the need of more detailed studies under an ongoing research program (Gardiner et al., 2009).

The Australian State of Victoria also utilizes a risk-response approach to assess transport infrastructure against climate change impacts. The Commonwealth Scientific and Industrial Research Organization (CSIRO) helped Victoria conduct a standard risk assessment of the transportation system. This qualitative assessment implemented the New Zealand Risk Management Guidebook (NZCCO, 2004).

SUMMARY OF APPROACHES

Comparing the main approaches identified in this study (UK, US and New Zealand), it appears most approaches are a slight variation from a basic risk management process. All approaches include an identification stage, a vulnerability analysis, and general feedback mechanisms. The frameworks from these three countries suggest a

© ASCE 2014

risk assessment to be performed after the vulnerability analysis, although this part is optional within the FHWA Climate Change and Extreme Weather Vulnerability Assessment Framework model. The three main frameworks all can be considered top-down approaches that are developed by government agencies for state or county application.

There are several small differences that set the US FHWA Climate Change and Extreme Weather Vulnerability Assessment Framework apart from the UK and New Zealand frameworks. Risk assessments are included as part of the Highways Agency and New Zealand frameworks, while it is optional in the FHWA vulnerability framework. Currently there is no requirement imposed by FHWA to state DOTs to implement the vulnerability assessment framework; where vulnerability assessments are expected to be implemented by local authorities in the UK and New Zealand.

REFERENCES

Commonwealth Scientific and Industrial Research Organization (CSIRO). (2007). Infrastructure and climate change risk assessment for Victoria. Report to the Victorian Government. Australia .

European Commission (EC). (2009). “Adapting to climate change: Towards a European framework for action.” European Commission, Brussels. (http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0147:FIN:EN:PDF)

European Commission (EC). (2013). “An EU strategy on adaptation to climate change.” European Commission, Brussels. (http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0216:FIN:EN:PDF)

European Environment Agency (EEA). (2012). “Climate change impacts and vulnerability in Europe: An indicator-based report.” EEA Technical Report No 12/2012, European Environment Agency, Copenhagen. (http://www.eea.europa.eu/publications/climate-impacts-and-vulnerability-2012).

European Environment Agency (EEA). (2013a). “Adaptation in Europe: Addressing risks and opportunities from climate change in the context of socio-economic developments.” European Environment Agency, Copenhagen. (http://www.eea.europa.eu/publications/adaptation-in-europe).

European Environment Agency (EEA). (2013b). “Support to transport and environmental assessments: Adaptation to Climate Change in the Transport Sector.” ETC/CCA Technical Paper 03/2013. European Environment Agency, Copenhagen. (http://cca.eionet.europa.eu/docs/TP_3-2013)

Federal Highway Administration (FHWA). (2009). “Highways and Climate Change. Literature Review: Climate Change Vulnerability, Risk Assessment, and Adaptation Approaches.” U.S. Department of Transportation. Washington, DC.

Federal Highway Administration (FHWA). (2012). "Climate Change & Extreme Weather Vulnerability Assessment Framework." U.S. Department of Transportation. Washington, DC.

Federal Highway Administration (FHWA). (2014). "Summary of FHWA Climate Adaptation Initiatives." U.S. Department of Transportation. Washington, DC. 2/21/2014. https://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/summary/index.cfm

Gardiner, L., Firestone, D., Osborne, A., Kouvelis, B., Clark, A., Tait, A. (2009). "Climate change effects on the land transport network volume two: approach to risk management." *NZ Transport Agency Research Report 378*. 142 pp.

Highways Agency. (2009). "Climate Change Adaptation Strategy and Framework." Department for Transport. http://assets.highways.gov.uk/about-us/climate-change/CCAF_Strategy_and_Vol_1_Rev_B_Nov.pdf

International Panel on Climate Change (IPCC). (2007). "Appendix I: Glossary." *Fourth Assessment Report.*

LaHood, Ray. (2011). "Policy Statement on Climate Change Adaptation." Department of Transportation. Washington, DC.

Ministry for the Environment (2008). "Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand". 2nd Edition. Mullan B; Wratt D; Dean S; Hollis M; Allan S; Williams T, Kenny G and MfE. Ministry for the Environment, Wellington.

National Research Council (NRC). (2008). "Potential impacts of climate change on US transportation." Transportation Research Board, Committee on Climate Change, US Transportation, National Research Council, Division on Earth and Life Studies. (http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf)

New Zealand Climate Change Office (NZCCO). (2004). "Coastal Hazards and Climate Change. A Guidance Manual for Local Government in New Zealand." 1st edition. 2nd edition revised by Ramsay, D, and Bell , R. (NIWA). Prepared for Ministry for the Environment. Wellington , New Zealand . http://www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual/.

Transport Planning Society. (2009). "Local Transport: Adapting to Climate Change." Local and Regional Adaptation Partnership Board. Winchester, UK. http://www.climatesoutheast.org.uk/images/uploads/Local_transport_adapting_to_climate_change_briefing.pdf

© ASCE 2014

Critical Infrastructure Resilience: A Baseline Study for Georgia

A.M. Carpenter[1]

[1]Georgia Tech Research Institute, Information and Communications Laboratory, 75 5th St NW, Atlanta, GA 30308; PH (404) 407-8044; email: acarpenter@gatech.edu

ABSTRACT

The Georgia Emergency Management Agency/Homeland Security (GEMA/HS) partnered with the Georgia Tech Research Institute (GTRI) to assess critical infrastructure and community-level resilience from the perspective of various critical infrastructure sectors. The goal was to establish a baseline understanding of current practices to create a picture of the strengths and weakness of the overall system. Based on a literature review, a review of current resilience initiatives, and interviews with statewide and Savannah-area critical infrastructure representatives, eight general recommendations for increasing resilience in Georgia were determined, including strengthening partnerships, identifying and encouraging strong leadership, encouraging trusted and secure information sharing, exercising for resilience by including more mid-managers and operators and inviting participants from across jurisdictions and sectors, encouraging continuity of operations planning, enhancing public awareness and outreach strategies, increasing cybersecurity efforts, and encouraging local governments to perform social vulnerability assessments to anticipate the impact of functional needs and other vulnerable households.

INTRODUCTION

In the last decade, due to increased awareness of threats to national security, significant resources have been invested in vulnerability assessments, preparedness, and response activities. The reality is that it is not practical to prepare for every possible worst case scenario. Furthermore, in a time when budgets are being reduced, it is necessary to think more strategically about the type of response activities undertaken in the event of a disaster that may cause a breakdown in critical infrastructure and impact our key resources. Increasing societal preparation and promoting community resilience are key factors in ensuring that communities are able to “bounce back” if there is a breakdown in critical infrastructure.

The Georgia Emergency Management Agency/Homeland Security (GEMA/HS) partnered with the Georgia Tech Research Institute (GTRI) to assess critical infrastructure and community-level resilience from the perspective of various critical infrastructure sectors and identify vulnerabilities that should be addressed in order to mitigate the effects of a breakdown. The goal was to establish a baseline understanding of current Critical Infrastructure/Key Resources (CIKR) practices to create a picture of the strengths and weakness of the overall system.

Based on a literature review, a review of current resilience initiatives, and interviews with Georgia statewide CIKR and Savannah area CIKR representatives,

© ASCE 2014

eight general recommendations for GEMA/HS for strengthening CIKR resilience in Georgia were determined.

This paper focuses on the lessons learned through the interview portion of this study. Interview subjects were chosen from various sectors including water, power, and gas utilities, transportation, airports, petroleum, healthcare, telecommunications, logistics, city services, emergency management agencies, nonprofits specializing in disaster relief, manufacturing, agriculture, and research. Interview questions included current practices that enhance and detract from resilience, barriers to resilience, development of contingency plans, kinds of exercises conducted, identification of sectors that are more and less prepared than others, identification of interdependencies and cascading effects between sectors, command structures and core values, leadership, community characteristics (social vulnerability of the population served), public outreach, and how to allocate resources to best improve resilience.

BACKGROUND AND LITERATURE REVIEW

Resilience and Critical Infrastructure. Since the terrorist attacks of September 11, 2001, Hurricane Katrina in 2005, and many other significant events, resilience has garnered increased attention as part of a larger strategy for homeland security. Focusing on the resilience, rather than strictly the protection, of critical infrastructure has the potential to improve the state's security and safety and reduce the burden of state government in this area. Increasingly, resilience has been added to command and control and prevention models of homeland security in order to leverage community resources. Critical infrastructure is particularly suited for a resilience-based approach for a number of reasons. These include institutional restructuring resulting in privatization, deregulation, and liberalization of many sectors in which CIKR function; the increased interconnectedness of systems illustrated by the emergence of a mega-infrastructure that is more vulnerable to failures; varied and unpredictable threats targeted at infrastructure; cost increases of protective measures as systems and threats become more complex; and a population that is increasingly dependent on infrastructure.

CIKR breakdowns can lead to catastrophic consequences due to complexity and tight coupling, which allow small problems to spiral into large crises or cause cascading failures. Therefore, the adaptive behavior of those at every level, including citizens, first responders, and middle managers, is critical. Strategies to promote resilience through these individuals include preparing first responders, improving business continuity plans, working with communities, working with private owners of CIKR, joint preparation (planning and exercises), joint training, and training leaders (Boin and McConnell 2007). Redundancy in a system is known to improve the likelihood that a system rebounds to its status quo, and to promote resilience. However, CIKR protection must balance anticipation and resilience. This means sinking fewer resources in specific defenses against risks that come out the formal assessment in favor of development of improving the knowledge base and operating experience of the relevant organizations through exercises and real-time intelligence gathering (deBruijne and vanEeten 2007).

© ASCE 2014

Critical infrastructure systems characterized as "lifeline systems" cross-cut most acutely with community-level resilience. These can be grouped into six principal systems of electric power, gas and liquid fuels, telecommunications, transportation, waste disposal, and water supply (O'Rourke 2007). These systems are necessary for economic and social well-being and security of residents and the community as a whole. These systems are also inherently interdependent due to shared geographical reach and operational interactions. O'Rourke gives the example of the World Trade Center's highly interdependent systems, which included water mains that were compromised, flooding rail tunnels, a commuter station, and an underground telecommunications switching station that was one of the largest in the world. Reliance on one method or system can lead to instability, whereas flexibility and redundancies allow for contingencies in case of a catastrophe, which is particularly evident in interdependent infrastructure systems such as the information technology and energy sectors (Cutter et al. 2008).

Resilience Concepts. Resilience is the ability of a system at any scale to rebound after a disturbance. A conceptual framework for resilience has been developed, consisting of interrelated technical, organizational, social, and economic ("TOSE") dimensions that contribute to and affect resilience (Bruneau et al. 2003). Technical and organizational factors relate to infrastructure and local agencies and governance and social and economic factors are entrenched in the community at large. All four TOSE dimensions describe contributions to a community's capacity for resilience. In addition, there are four resilience dimensions (the "four R's") by which resilience can be measured, including robustness, redundancy, resourcefulness, and rapidity (Bruneau et al. 2003). Robustness refers to the overall strength of a system, or its ability to withstand a stressor without failing. Redundancy is the existence of substitutable elements in the system, allowing continuity of necessary services even when some elements fail. Resourcefulness includes the ability to plan and implement disaster recovery based on established priorities and goals. Rapidity is the simply the ability to carry out these activities quickly. The TOSE dimensions and community-level disaster resilience in general can be evaluated along each of the four R's.

Resilience of systems also depends on factors beyond the technical, including managerial, infrastructural, and cultural. Each element is important, but cultural factors are deceptively important. Three core aspects of resilience are said to include, quite simply, the ability to prevent something bad from happening (avoidance), the ability to prevent something bad from becoming something worse (survival), the ability to recover from something bad before it becomes even worse than before (recovery) (Jackson 2010). Overall, capacity, flexibility, tolerances, and inter-element collaboration support these three capabilities. Jackson distinguishes between human-oriented and product-oriented infrastructures, the former includes the "lifeline systems" while the latter includes manufacturing, logistics, and related systems.

Case studies have informed many additional facets of resilience. A study of Hurricane Katrina demonstrated the catastrophic consequences that occurred because of critical infrastructure failures and the limited effectiveness of a top-down crisis management approach (Boin and McConnell 2007). In New Orleans, complexity of systems and tight coupling, or overreliance on nonredundant systems, led to

© ASCE 2014

cascading effects across multiple sectors, thus escalating the crisis. The failure of levees, dykes, and pumps damaged or submerged many needed resources, such as police facilities, National Guard barracks and equipment, hospitals, and power and communication centers (Westrum 2006). According to Boin and McConnell, an effective public response cross-cuts many resilience factors, in particular preparing first responders, promoting business continuity planning, working with community groups, working with private owners of critical infrastructure, joint preparation (planning and exercises), and leadership training. Strategies to promote the resilience of these groups will help influence adaptive behavior of all citizens, responders, and community leaders.

Factors that complicate a resilience approach in many critical infrastructure sectors include economic, social, and regulatory shifts such as privatization, deregulation, and liberalization, and a decrease in competition among providers (deBruijne and vanEeten 2007). While regulating and managing organizations are increasingly fragmented, interconnections between infrastructures tend to be increasing or intensifying. In order to better protect critical infrastructure, anticipation and resilience must be balanced, or fewer resources should be devoted to defending against risks in favor of activities that expand the knowledge base and operating experience of organizations. This could be achieved through exercises and intelligence gathering, for example.

Addressing the specific reliance on the three interdependent mega-infrastructures of energy, telecommunications, and transportation, researchers found that major weaknesses in capacity (energy consumption outpacing transmission expansion, for example) dovetail with increased demand from both the telecommunications and transportation sectors (Amin 2002). The grid must be reliable to power diverse consumers such as telecommunications command centers, user devices, and intelligent transportation systems. One method of combatting ongoing and cascading crises is to decentralize information, or empower local centers to use their own resources to resume operations during a service outage. This is inherently an adaptive strategy. Research and development was also cited as a resilient practice.

Finally, in addition to resilience in CIKR systems and operations, community-level resilience should also be taken into account. Community resilience is complex, generally characterized by a lengthy list of factors such as social, economic, institutional, infrastructure, community competence, and ecological factors. In terms of CIKR sectors, all community factors can have a director or indirect effect on a sector or facility's ability to rebound, in part because critical staff members are also members of the community. Therefore factors related to community resilience should not be discounted in a facility's or sector's resilience approach.

METHODOLOGY

In 2012 and 2013, facility managers, safety specialists, and other representatives of Georgia-based critical infrastructure sites were interviewed. This included state, local, military, and private facilities. The first set of interviews targeted statewide CIKR or CIKR that serve the entire state. The second set of interviews targeted the Savannah/Chatham County area in order to provide an in-

© ASCE 2014

depth overview of resilience factors and interdependencies at a smaller and more comprehensible scale. Savannah was chosen due to the high risk of natural and manmade disasters, most notably hurricanes, as well as the concentration of high-profile CIKR, such as the Port of Savannah. Based on previous work in the area, it was known that Savannah's most pressing vulnerability is considered to be a hazardous materials incident in one of the industries along the Savannah River. By contrast, the city is well prepared for a hurricane.

Interviews were requested with about 30 individuals, of which most consented to an interview. Interview subjects were chosen from various sectors including public works, power and gas utilities, transportation, airports, petroleum, healthcare, telecommunications, logistics, city services, emergency management agencies, nonprofits specializing in disaster relief, manufacturing, agriculture, and research (Table 1). Subjects represented 12 of the 18 CIKR sectors identified in Homeland Security Presidential Directive (HSPD 7). Sectors from which interview subjects were not identified, including communications and information technology, were discussed in significant depth in several other interviews. Interview questions included current practices that enhance and detract from resilience, barriers to resilience, development of contingency plans, kinds of exercises conducted, identification of sectors that are more and less prepared than others, identification of interdependencies and cascading effects between sectors, command structures and core values, leadership, community characteristics (social vulnerability of the population served), public outreach, and how to allocate resources to best improve resilience. Findings are organized below by these topics.

Table 1. Interview Subjects by CIKR Sector

CIKR Sector (based on Homeland Security Presidential Directive 7)	Number of Interview Subjects
Agriculture and Food	1
Defense Industrial Base	3
Energy	3
Healthcare and Public Health	1
Water	2
Chemical	2
Commercial Facilities	4
Critical Manufacturing	3
Emergency Services	6
Postal and Shipping	1
Transportation Systems	2
Government Facilities	3

FINDINGS

Assessment of the Resilience of Current Practices. In many cases, the practices that currently enhance resilience were related to the design of the system itself,

© ASCE 2014

including redundancies and overdesign. Other practices included the current risk management and assessment processes, exercising with local and state authorities, mutual aid relationships, public outreach, business continuity planning, and public-private partnerships (where these exist). Many sectors are required to develop and exercise plans due to federal regulations (for example, the airport and facilities on the Savannah River). In Savannah, continuity of operations plans that are in place tend to be robust. Chatham County and City of Savannah are particularly strong in this area and the Chatham County Emergency Management Agency (CEMA) has developed a Continuity of Operations Planning template for municipalities and businesses.

Public-private partnerships that were specifically cited included the Governor's Homeland Security Task Force, the Atlanta Police Department Task Force, Atlanta Metropol, and the Business Executives for National Security (BENS). Partnerships in Atlanta were said to be very strong with good support from GEMA/HS. Most felt that there were no political or leadership challenges toward enhancing resilience. Decision makers at most levels are supportive and have a growing interest in understanding and addressing interdependencies.

Consistently, interview subjects in Savannah mentioned existing partnerships or relationships with many other agencies, facilities, and sectors as the most significant practice that enhances resilience. Relationships exist between local, state, federal, military, private, and nonprofit organizations, often facilitated by CEMA. It was acknowledged that partnership building requires a large level of effort. In the past ten years, partnerships have been a regional priority and have flourished. However, partnerships are needed between the corporate sector and government as well as within the corporate sector at a regional level. Some facilities, in particular smaller organizations, do not realize the value of these relationships and do not seek them out, to their own detriment. Size of organization was a limiting factor in other areas as well, such as planning, training, and exercises.

In terms of practices that detract from resilience, the prioritization of resources was thought to be an issue impacting the ability of systems to rebound. Although this is necessary, lower priority resources may have a disproportionate or cascading effect on other systems. Complacency was also an issue; for example, in Savannah there has not been a direct hit from a hurricane in 80 years, leading to lax planning in some instances. Finally, CIKR are often focused on business continuity and lack the resources to do more in terms of resilience, such as identifying interdependencies. Furthermore, small businesses are less likely to pre-plan at all due to lack of resources.

Barriers to Resilience. While some felt that there are few or no barriers to resilience in their sector, the main barriers cited were resources and time needed for planning. This was generally manifested in a lack of dedicated staff able to maintain protection activities and engage in resilience building. This was not universally true, however, as some organizations have devoted significant resources to build resilience, in part due to the potential fiscal benefits.

After resources and time, information sharing and communications were the most prevalent barriers. For some sectors, protecting sensitive information makes this impossible. This has been true for regional and national initiatives as well. The

© ASCE 2014

PNWER program attempted to create a database of interdependencies but was stymied due to competition and distrust among and within sectors. In addition, the U.S. Department of Energy attempted a similar information database without success.

Another barrier was the lack of strong pre-existing relationships. Pre-planning and regular communications between private, public, and non-governmental organizations is critical in a disaster response. The responses were mixed, however, and many responded that their organization works well with the public sector (national, state, and local) and feel that those relationships benefit them. The types of activities necessary were said to be first establishing and maintaining relationships and then increasing capacity and enhancing technology and communications systems to make processes and procedures more efficient.

A lack of standardized methods for protection was also an issue. For the energy sector, North American Electric Reliability Corporation (NERC) standards are in use, but are not as rigorous as those employed overseas. Overlapping jurisdictions was also a barrier to resilience. This can be best illustrated by the natural gas utility sector, where multiple providers may serve a county or even a neighborhood. This is also an issue where large service providers in small geographic areas must interface with many local governments.

In Savannah, additional barriers were complacency, complexity of systems, turf battles, meeting the needs of residents in unincorporated areas, aging infrastructure, and housing plans. Resources were mentioned, though far less frequently than in interviews with statewide CIKR. Savannah has not been in the path of a Category 2 hurricane since 1979 (Hurricane David) and the last direct hit by a Category 3 storm was in 1898, leading to complacency among residents about the possibility of a destructive hurricane, and complacency about preparedness in general. Complacency combined with a lack of knowledge and inability to comprehend the complexity of interrelating CIKR systems has led to insufficient planning in some sectors, despite the inherent financial risks. For municipal and county governments, political barriers, including turf battles between contiguous or overlapping jurisdictions was also an issue. Unincorporated areas rely on memorandums of understanding and mutual aid agreements in case of a disaster, however, those agreements are likely to falter in a major disaster where resources are scarce and jurisdictions must also meet the needs of their home populations. For organizations with a national or multinational footprint, adaptability of organization policies to meet local needs was also a barrier.

The age of infrastructure in the area was considered a barrier to resilience, with replacements needed to prevent failures from normal wear and tear let alone the stress of a disaster. Long-term post-disaster housing plans were seen as a barrier as well, particularly in the private sector, where staff must be able to return to work quickly to reestablish operations. Without a housing plan in place, it is not known whether hotels, shelters, and other housing would be available resources, a major barrier to developing and carrying out continuity of operations plans.

Overall, the most pessimistic attitude was that most sectors do not fully understand the vulnerabilities they face and the complexity of systems and thus are unable to become resilient or move beyond protection. In addition, the metro Atlanta area is better prepared while rural areas tend to look to the state during a recovery.

© ASCE 2014

There are tremendous resources and partners from private and nonprofit sectors in Atlanta. The government understands the critical role of CIKR in Atlanta and the need to restore the metropolitan economy in a crisis situation.

A summary of the most prevalent strengths and weaknesses compiled during interviews is shown in Table 2, below. The table includes practices that enhance or detract from resilience as well as barriers to resilience.

Table 2. Current Resiliency Strengths and Weaknesses in Georgia

Resiliency Strengths	Resiliency Gaps and Barriers
Redundancies	Complexities
Overdesign of systems	Age of infrastructure
Risk management and assessment practices	Complacency
Multi agency exercises	Overlapping jurisdictions
Mutual aid agreements	Lack of information sharing
Business continuity planning	Too-narrow focus on continuity of operations/Not enough planning
Public-private partnerships	Lack of strong pre-existing relationships
Public outreach	Standardization of methods of protection
	Lack of financial and staff resources

Contingency Planning. Most interview subjects had contingency plans for all identified risks. In some cases, certain types of plans are required by regulating agencies, but additional plans above those requirements are also in place. Others mentioned practices such as utilizing an all-hazards approach and modeling scenarios as well as risks. It was noted that plans should be adaptable and flexible. In the private sector, procurement and permitting is often a delaying factor that can detract from being adaptive. Mutual aid and contracting agreements should be made ahead of time to avoid this. Redundancies are particularly expensive and therefore mutual aid planning is beneficial and cost-effective. In Savannah, long-term recovery planning (for example, long-term post-disaster recovery) was considered to be lacking.

Exercises. The responses to questions about the types of exercises conducted and with whom exercises are conducted were mixed, some sectors do not train with local responders but frequently exercise internally and some frequently exercise with mutual aid and local responders. Internally, contingency plans are typically drilled often.

In Savannah, although the county emergency management agency holds two to three exercises and participates in about 12 exercises per year and many other

© ASCE 2014

sectors hold their own additional exercises, some sectors believed that there are limited opportunities to exercise and exercises are not coordinated to maximize effectiveness. Others felt that there is unnecessary duplication of exercises due to poor coordination, with consolidation of exercise schedules in related sectors a possible solution.

Relative Resilience of CIKR Sectors. Banking and finance was mentioned as a sector that is extremely resilient, chiefly because they are required to resume operations in a short amount of time after a disturbance. Because of this, regulations were said to be good motivators for resilience. The health sector was also mentioned due to certain aspects of the Joint Commission hospital accreditation program that require lifeline infrastructure backups. Others mentioned included power and telecommunications, as these sectors have a larger, even national, service area and can call upon resources from outside of the impacted areas to respond to a disaster in Georgia. These sectors also stage resources to prepare for potential disasters and exercise often.

Subjects were overwhelmingly hesitant or unable to name a sector that was less prepared than others, perhaps indicating an acceptable level of resilience in CIKR in Georgia. Sectors that are potentially less resilient included the energy sector and private industry, particularly the chemical production sector.

Interdependencies. A few sectors were interdependent with almost every other sector, including energy, electrical power, and communications, although most sectors have backup systems in place to become self-sufficient in a disaster. In addition to these lifeline sectors, others were interdependent with at least one other sector, including transportation (a frequent response, though not universal), water and sewage, public safety, health care, government, military, business, food supply, logistics, and banking and finance.

In Savannah, the military and chemical presences and the port also have the potential to cause major disturbances in other sectors. Many CIKR sectors are positioned along and rely on the Savannah River, leading to significant and costly interdependencies. The chemical producers along the river would disrupt a large number of sectors in the case of a spill. Other transportation sectors, including the highly trafficked I-95 corridor, were also frequently cited. A breakdown in the road transportation sector would impact the airport, port, and rail (multi-modal transportation links) as well as sectors outside of the transportation domain, such as public works.

Command Structure and Core Values. Most respondents reported that a set of core values, ethics, and priorities are in place to help guide decisions and actions in case of a collapse of the command system. For private industry, this is generally a corporate responsibility that is pushed down to local facilities. If the corporate footprint is large enough, this allows for support and mobilization of resources from outside the impacted area. The emphases on employee and public safety and serving the customer in CIKR are part of the values of many CIKR providers. In some cases, such as the airport and hospital sectors, these plans are highly formalized and are

© ASCE 2014

carried by staff during any emergency. Others have continuity of operations and devolution plans that cover mission, responsibilities, and central functions. Utility companies are unique in their reliance on middle management and individual contributors in day-to-day operations, with a reduced reliance on the top of the hierarchy, a system that would seem to allow greater adaptability and resilience in the entire system.

Leadership. Strong leadership within responding agencies and within sectors was seen as a necessary component of resilience. Representation on national councils, such as the U.S. Department of Homeland Security's Critical Infrastructure Partnership Advisory Councils (CIPAC), was seen as beneficial at the local and state level. These councils bring together public and private stakeholders to improve communications and capacity.

CEMA has organized a command policy group, consisting of leaders in emergency management, county government, municipal government, schools, sheriffs, and other local leaders to encourage preparedness and resilience. This group regularly communicates during special events. Interviewees also highlighted the efforts of local executive management in private facilities such as the airport and the efforts of faculty at Savannah State University's Homeland Security and Emergency Management program. Savannah State works closely with various CIKR to place interns and graduates and foster local emergency management talent.

Community Resilience. Interview subjects were asked what characteristics of their community or service area decrease resilience (in terms of vulnerability) or increase resilience (in terms of preparedness). Vulnerability concerns given by interview subjects included complacency or lack of experience in disaster recovery as well as tending to special populations such as functional needs patients, the elderly, poor households, homeless populations, and non-English speaking populations. A lack of household preparedness and pre-disaster planning and inadequate insurance coverage were also concerns. As seen in Hurricane Katrina and Hurricane Sandy, many households have insufficient insurance coverage or assets to rebuild after a disaster. In Savannah, almost 30 percent of households are below the poverty line. These poor households generally lack liquid assets or other means to recover after a disaster. Further, temporary residents such as Savannah College of Art and Design (SCAD) students and a steady stream of tourists year-round complicate resilience.

Public Outreach. When asked about public outreach and awareness activities undertaken to improve household- and community-level resilience, many sectors provided their own examples as well as third-party examples such as FEMA's ready.gov, GEMA/HS's Ready Georgia, the American Red Cross Ready Rating, the Safe America Campaign to Enhance America Preparedness, Points of Light's Good & Ready campaign, the U.S. Chamber of Commerce's disaster preparedness programs, and Voluntary Organizations Active in Disaster (VOAD). Many outreach activities undertaken by CIKR focus on safety (for example, use of 811 "Know What's Below" and tips for reporting security and safety concerns around facilities). Household preparedness and activities focused on business continuity and community

© ASCE 2014

resilience were also reported. In addition to promoting household preparedness among constituents and customers, many facilities and major employers also have awareness and preparedness campaigns for employees. Some public entities have embraced social media such as Facebook and Twitter for awareness and alerting. Social media was also believed to be a challenge, as misinformation can spread quickly. In Savannah, interviewees also mentioned K-12 outreach activities and working with the faith-based community to spread awareness.

Improving Overall Resilience. Finally, interview subjects were asked how they would allocate additional resources to improve resilience. They were allowed and encouraged to be as ambitious as they liked in their responses. Many would simply hire more dedicated staff, particularly for relationship building. Other responses included holding more exercises, hardening and backing up infrastructure (for example, laying "dark fiber" for telecommunications), more research and assessment, more planning, more citizen preparedness activities, increasing media coverage of emergency planning, and increasing the level of trust in the community through a bottom-up approach that could also decrease complacency.

The above findings from the state and the Savannah region were used to create the recommendations for the state, found in the following sections

RECOMMENDATIONS AND DISCUSSION

Based on the literature review, a review of existing resilience initiatives, and the interviews with state and Savannah area CIKR representatives, several recommendations for strengthening CIKR resilience in Georgia were determined. These are:

- Strengthen partnerships, including public-private partnerships as well as partnerships between local governments. When possible, encourage partnerships between private sector entities. Consider formalizing a statewide CIKR working group.
- Identify and encourage strong leadership in CIKR.
- Encourage trusted, secure information sharing using Protected Critical Infrastructure Information (PCII) guidelines, the Homeland Security Information Network (HSIN), CIKR Information Sharing Environment (ISE), or other processes and systems.
- Exercise for resilience by including more mid-managers and operators and inviting participants from across jurisdictions and sectors.
- Encourage continuity of operations planning in all sectors and in facilities of all sizes.
- Enhance public awareness and outreach strategies.
- Continue cybersecurity efforts with input from CIKR sectors.
- Encourage local governments to perform social vulnerability assessments to anticipate the impact of functional needs, elderly, impoverished, non-English speaking, and other vulnerable households.

It is evident that resilience has become the guiding principle for improving critical infrastructure security. The interviews highlighted the strengths and potential

© ASCE 2014

areas of weakness at the state and local level in Georgia. Overall, resilience in Savannah was strong, with many best practices for resilience identified, such as formal and informal public-private partnerships and strong leadership from the county emergency management agency. Savannah is well prepared for a natural disaster and has extensive resources for responding to a chemical spill. At present, climate change and sea level rise were not concerns identified or incorporated into plans in Savannah or at the state level. Other gaps include complacency, an aging infrastructure, a narrow focus on business continuity rather than resilience, the lack of dedicated staff who are able to maintain protection activities and engage in relationship building and other resilience-enhancing activities, the need for better information sharing and communications, and political barriers, including turf battles between contiguous or overlapping jurisdictions. The last issue was underscored during a major winter storm in January 2014, where poor coordination and communications left many Atlanta commuters stranded on roadways overnight. As severe weather events such as this increase in frequency, it is more important than ever that a statewide resilience approach is adopted, exercised, and adapted as necessary.

REFERENCES

Amin, M. (2002). "Toward Secure and Resilient Interdependent Infrastructures." *Journal of Infrastructure Systems*, 8(3), 67-75.

Boin, A., and McConnell, A. (2007). "Preparing for Critical Infrastructure Breakdowns: The Limits of Crisis Management and the Need for Resilience." *Journal of Contingencies and Crisis Management*, 15(1), 50-59.

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., Shinozuka, M., Tierney, K., Wallace, W. A., and VonWinterfeldt, D. (2003). "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities." *Earthquake Spectra*, 19(4), 733-752.

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., and Webb, J. (2008). "A place-based model for understanding community resilience to natural disasters." *Global Environmental Change*, 18, 598-606.

deBruijne, M., and vanEeten, M. (2007). "Systems that Should Have Failed: Critical Infrastructure Protection in an Institutionally Fragmented Environment." *Journal of Contingencies and Crisis Management*, 15(1), 18-29.

Jackson, S. (2010). *Architecting Resilient Systems*, John Wiley and Sons, Inc., Hoboken, NJ.

O'Rourke, T. D. (2007). "Critical Infrastructure, Interdependencies, and Resilience." *The Bridge*, 37(1), 22-29.

Westrum, R. (2006). "All coherence gone: New Orleans as a resilience failure." *Proc., 2nd Symposium on Resilience Engineering*, Resilience Engineering Association, Sophia Antipolis, France.

© ASCE 2014

Sea-level Change Considerations for Marine Civil Works - COPRI Committee Update on Best Practices

Jean O. Toilliez[1], Todd J. Mitchell[2] and Austin Becker[3]

[1] Ben C. Gerwick, Inc., 1300 Clay Street, 7th Floor, Oakland, CA 94612; PH (510) 839-8972; FAX (510) 839-9715; email: jnot@gerwick.com

[2] Fugro Pelagos, Inc., 4820 McGrath Street, Ste 100, Ventura, California, 93003; PH (805) 650-7000; FAX (805) 658-6679; email: tmitchell@fugro.com

[3] University of Rhode Island, Department of Marine Affairs and Landscape Architecture, College of the Environment and Life Sciences, Coastal Institute Room 213, 1 Greenhouse Road, Suite 205, Kingston, RI 02881; PH (401) 874-4192; FAX (401) 874-2156; email: abecker@uri.edu

ABSTRACT

The Coasts, Oceans, Ports and Rivers Institute (COPRI) within the American Society of Civil Engineers (ASCE) is developing a Manual of Best Practice to address the inclusion of sea-level change considerations during the design of marine civil works. The Committee serves the needs of all stakeholders involved in a marine project and designers and engineers in particular. The manual will provide designers and engineers with systematic methods for incorporating sea-level change projections into their project designs. Studies use different methods and data for calculation and thus global mean sea level rise estimates for 2100 range from 0.6 – 2.0 meters. In addition, planning for marine civil works should consider local sea level variations. In response, this Committee is developing recommendations to assist in managing design factors, uncertainty, and to a certain extent, measure implementation. This paper provides an overview of these issues the recommendations that the Committee is developing.

INTRODUCTION

Sea level change (SLC) presents designers of marine civil works with the problem of determining cost-effective life-cycle adaptation and/or mitigation solutions. Marine civil works includes nearshore and offshore infrastructure and is defined as those structures and features connected with the operation and protection of ports, such as: wharves, docks, piers, revetments, breakwaters, jetties, seawalls, channels, bulkheads. Although trends suggest a global rise in mean sea-level, conclusions about the local rate of change and projected impacts remain inconsistent between studies. The number of contributing factors and their impacts make quantifying the rate of relative sea level change (RSLC), on the local level, very difficult. However, the difference between the mean global SLC and the RSLC on the local level can be profound. In fact, some areas could even see a decrease in sea levels, while others see a rise that far exceeds the global mean. Long time horizons further complicate matters, especially when designing marine civil works projects that have useful design lives ranging from 50 to 100 years and actual useful lifespans that often extend beyond 100 years. This presents a great challenge for marine civil works owners and to designers and engineers providing professional advice. Therefore, the professional engineering community needs to develop and implement systematic and practical methods for assessing the impacts of RSLC on a marine civil work project ("project").

© ASCE 2014

This paper lays out the initial findings and recommendations from a Coasts, Oceans, Ports and Rivers Institute (COPRI) Ports and Harbors sub-Committee on SLC ("Committee") charged with developing a manual of best practice for designers and engineers of marine civil works to address RSLC. It begins with an overview of the COPRI initiative, then provides background on the current state of SLC science, including a discussion of the various factors that contribute to local variations in rise and methods to assess these effects for a given site. Next, it provides an overview of the recommendations that the Committee is developing for marine civil works. These consist of several methods to ascertain RSLC, as opposed to simply appropriating SLC projections from global models, and three main steps that engineers, project developers, designers, and other stakeholders should follow in the initial stages of planning for long-life marine civil works projects, as follows: Step 1. Provide context to stakeholders; Step 2. Survey, analyze and forecast sea level change and other factors; Step 3. Manage uncertainty and implement adaptive measures. To make the recommendations more salient, the paper then provides two examples of hypothetical projects that would be appropriate for the type of review the Committee recommends and is currently developing. Finally, it concludes with some final thoughts and addresses next steps the Committee will take toward completion of the manual.

COPRI INITIATIVE

In 2011, COPRI formed a task sub-Committee on SLC ("Committee") to consider challenges associated with this critical issue and the potential impacts on marine civil works. COPRI charged the sub-Committee with the task of leveraging existing knowledge on SLC to provide suggestions and guidance to structural and coastal engineers and designers. One of several groups in the engineering community focusing on SLC,[1] the intent of this Committee is to provide a "technical road map" to aid designers in managing a growing amount of data published by international organizations, inter-governmental panels and state and federal entities; to define a framework in which to analyze and quantify the impact of SLC on the structure; and to suggest ways to deal with uncertainty and in general, to make informed decisions regarding any adaptive measures they plan to build into the project.

Context

Marine civil works are complex and dynamic systems due to their location, economic potential and social influence. In the case of seaports and marine civil works in general, there exist strong economic, environmental and social incentives support the development of tools and methods to provide long-term protection against changing climate conditions (Becker et al. 2013). As climate conditions worsen, these incentives grow.

Objectives

The Committee is currently developing a Manual of Best Practices (MBP), of which this paper constitutes a cursory draft summary. Its purpose is to assist designers and stakeholders with identifying solutions to address impacts of RSLC. Starting with a succinct primer on the physics of SLC, the MBP provides a methodology and resources to identify, analyze and respond to the impact of RSLC at a given site that should be considered by Designers. While the MBP will focus on a specific subset of structures most typically encountered in a seaport setting, the

[1] Including but not limited to: sea-level rise group; ASCE sea-level rise and coastal infrastructure

© ASCE 2014

methods presented are applicable to other types of coastal and near-shore structures, either structural or non-structural in nature.

SEA LEVEL CHANGE

Mean SLC depends on many parameters. As schematized in Figure 1 adapted from (Oerlemans 1989), greenhouse gas emission drive atmospheric changes that affect oceans in many ways, including thermal expansion, ice sheet degradation, melt of glaciers. In turn, these affect ocean volume and temperature. With all of the climate change drivers indicating an upward trend, including carbon release following the most conservative trajectories proposed by the Intergovernmental Panel on Climate Change (IPCC 2007), a large body of research suggests that SLC will increase and may accelerate over time, with upper-bound long-term values for 2100 nearing 2 m as measured from 2000 – see for instance (NRC 2012; A. Parris et al. 2012; USACE 2011) among others. Of course, sea level will continue to rise at an accelerated rate well beyond 2100.

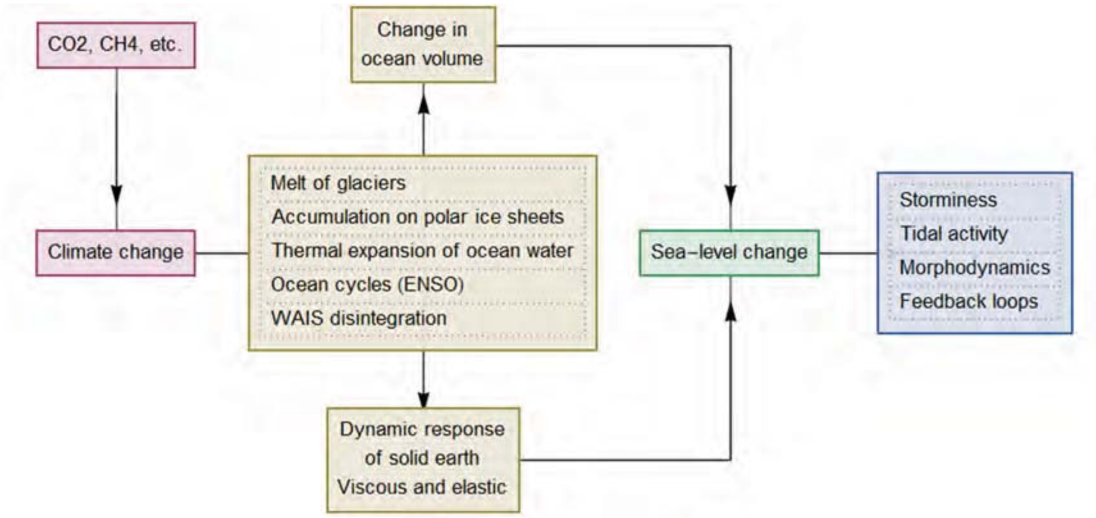


Figure 1. Most important processes that determine a change in sea level, with selected consequences on meteocean parameters. Material adapted from an original schematic provided by (Oerlemans 1989).

Converging Long-term Projections

Due to the large number of parameters governing long-term sea-level trends, a significant level of uncertainty surrounds future estimates, customarily provided as central estimates and confidence band triplets. Nonetheless, projection data shows a consistency in the general upward trend across publications and compilations, as well as in the use of projections by various public agencies, as shown in **Error! Reference source not found.**.

Over time, long-term projections, defined here as those expected by 2080-2100 most of the values range from 0.6 to 2 m; with a mean value of approximately 1 m from 2000 levels by 2080-2100. For instance, while the 1986 National Research Council (NRC) report issued recommendations with limited computational and data-sensing capabilities, their projections were in remarkable agreement with their 2012 counterparts. In a similar fashion, recently published articles (Rahmstorf 2010; Grinsted, Moore, and Jevrejeva 2009; Jevrejeva, Moore, and Grinsted 2012) confirm results from other studies performed by (Hoffman, Keyes, and Titus

© ASCE 2014

1983) and (Revelle 1983). As such, the figure illustrates the growing amount of data on climate change and SLC, the consistency across published results, and the growing body of public agencies moving forward to establish design guidelines. The Committee will regularly update this chart as scientific evidence is published.

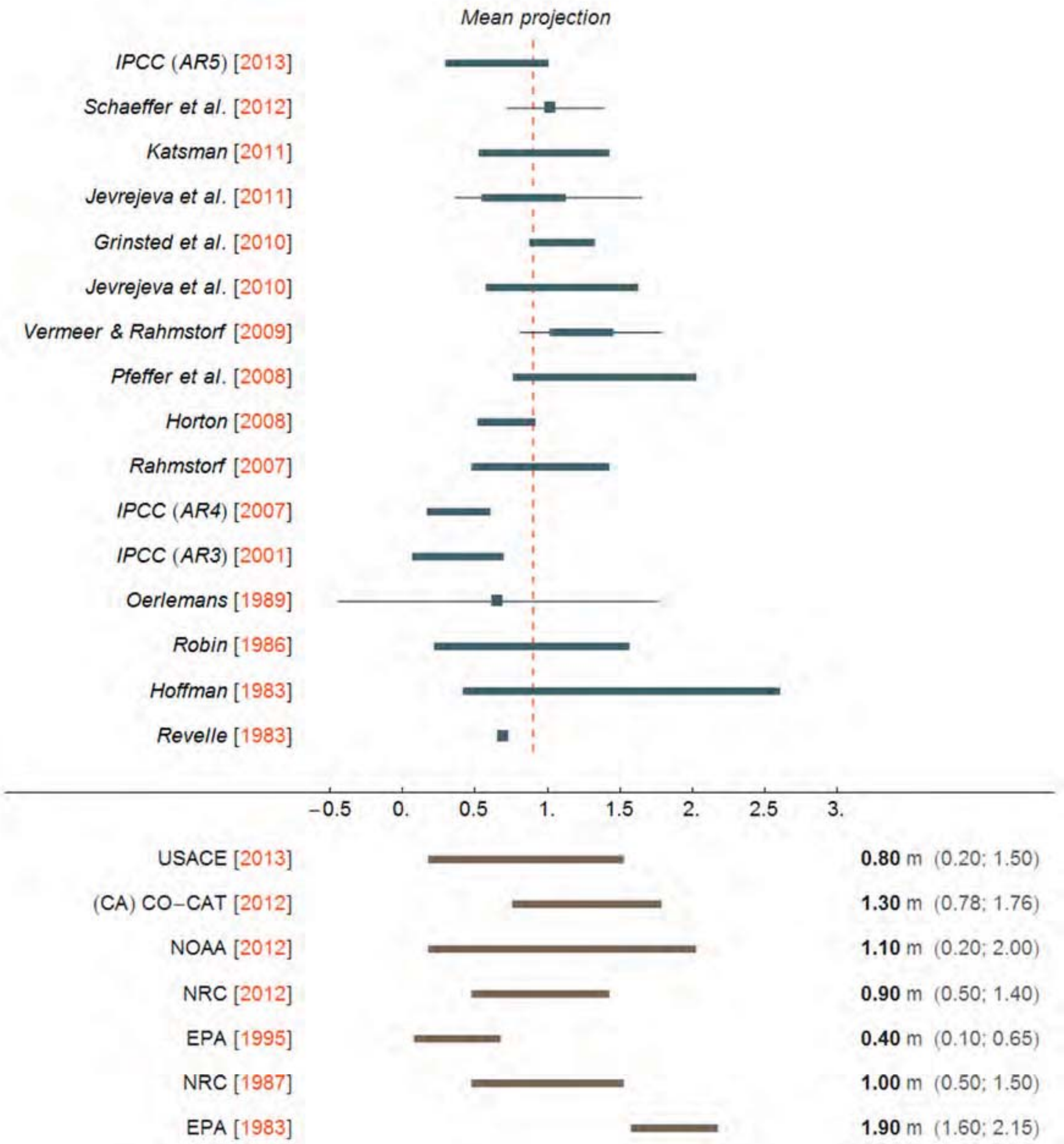


Figure 2. This figure illustrates, in a chronological manner, global mean SLC projections published in notable independent studies, shown with thick (mean estimates) and thin (confidence bands) blue bars (**top**); and compilations, with thick brown bars (mean estimates; multiple scenarios) (**bottom**). Long-term projections are converging toward a mean (arithmetic) value of approximately 1 meter from 2000 levels by 2100. This dynamic figure illustrates the growing amount of data on climate change and SLC, the strong consistency across published results, and the growing body of public agencies moving forward to establish design guidelines. This Committee does not endorse any particular guidance for addressing long-term SLC.

© ASCE 2014

A comment on the relationship between guidelines and independent studies is in order. Guidelines are compilations of independent studies. Unlike the latter, the former do not seek to establish independent SLC projections. For instance, states have increasingly disseminated guidelines for addressing climate change and SLC by relying on a few select scientific expert panels to establish baseline values. The State of California's Climate Action Team (Cayan et al. 2010) based their projections chiefly on (Vermeer and Rahmstorf 2009); while the State of Washington's Department of Ecology elected to base RSLC projections on the recent (NRC 2012) publication.

Notable Publications and Guidelines

The IPPC reports projections of a 0.32 – 0.98 m rise by the year 2100 (IPCC 2013). These projections are larger than those reported in the two previously issue reports, (IPCC 2007) and (IPCC 2001), and add weight to an increased level of confidence in the scientific community of the significance of accelerating climate change trends. All these estimates exclude contributions from "rapid ice" scenarios, which may drive long-term projections significantly higher - the interested reader may turn to the recently published NRC report on abrupt impacts of climate change (NRC 2013). As noted in the latest IPCC report (IPCC 2013) "larger values [due to abrupt impacts of climate] cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise". While there exists a larger body of articles and guidelines than those listed in **Error! Reference source not found.**, the list compiled below does not constitute any endorsement for using one such study or guideline over another.

MEAN SEA LEVEL CHANGE AND OTHER FACTORS AT THE LOCAL LEVEL

This section provides a short primer on SLC physics and some specific Committee recommendations (currently in development) for assessing RSLC on a site-specific basis.

Mean Sea Level Components

Mean SLC is only one component of a site-specific total water level (TWL) at a given site. As stated in (Ruggiero 2013), the TWL can be broken down in five main components:

$$\mathrm{TWL} = \mathrm{UT} + \mathrm{MSL}(t) + \eta_{\mathrm{A}} + \eta_{\mathrm{NTR}} + \mathrm{R}$$

UT is the vertical land up-thrust; $\mathrm{MSL}(t)$ is the local mean sea level, with a SLC component; η_{A} is the tidal component; η_{NTR} is the non-tidal residual water level (i.e. surge); and R is the vertical component of the wave run-up, which includes the wave setup and swash oscillations around the wave setup. Feedback loops may in time exacerbate one or more parameters in response to a change in MSL, or vice versa. These phenomena should therefore be the subjects of a careful site-specific assessment, which in some cases may require sensitivity studies, as outlined below.[2]

[2] Note that the software packages and models referenced throughout this section may be found through the Coastal and Hydraulics Laboratory (CHL), Environmental Research and Development Center (ERDC), USACE, online at http://chl.erdc.usace.army.mil/.

© ASCE 2014

Compounding Phenomena at the Local Level

Land Upthrust and Subsidence

As evidenced by the results on historical sea-level trends compiled by NOAA, not all coastal locations are affected by SLC by the same degree. For example, significant land upthrust due to post-glacial rebound in Alaska are mainly responsible for downward trends in MSL in Skagway, AK, exhibiting a -17.12 mm/year linear trend based on mean sea level data gathered from 1944 to 2006 (NOAA CO-OPS station 9452400). Estimates for upthrust can be gathered from USGS and NOAA databases, along with site-specific land- and air-based survey efforts. Similarly, subsidence due to delta settlement and prolonged modifications in the sediment supply system have made RSLC at Grande Isle, LA one of the fastest rising in the nation, with the latest estimate for sea-level change pointing at 9.24 mm/year (NOAA CO-OPS station 8761724).

Recommendation: Obtain estimates for upthrust and subsidence from USGS and NOAA databases, along with site-specific land and air based surveys to inform local projections for RSLC, if possible.

Simultaneity of Events

Unusually high spring tides, known informally as "king tides," stacked with even modest variations in sea level can induce non-linear response from structures with small freeboard (abrupt change from no flooding to flooding). Similarly, fresh water input from heavier rain storm events can add significant burden to sewage and storm water drain systems, as evidenced by the results compiled by the Pacific Institute (Heberger and others 2009) and as illustrated by Newport Beach's Balboa Island emergency storm drain crew[3]. Tidal events are deterministic and can be fully assessed within 18.6 years through the use of historical data. Likewise, changes in precipitation patterns due to climate change can also drive stronger and more frequent rain storm events, which may add burden to an existing storm water drain system during a storm surge event. This can be particularly problematic for projects located near a river outlet, where extreme river stages can amplify an incoming storm surge.

Recommendation: Perform inventory of nearby riverine discharges that may increase burden on the project. Obtain estimates for water levels from nearby NOAA stations. Complement with site-specific modeling of combined storm surge/extreme river stage using numerical inundation models allowing for evaluating a combination of events, such as TUFLOW, HEC-RAS, Mike 11, etc.

Storm Surge and Tidal Amplitudes

In their paper, (Atkinson, McKee Smith, and Bender 2013) provide evidence of the potentially significant consequences of non-linear response of hurricane storm surge and SLC in the Gulf of Mexico region. The simulations show that the relationship between storm surge and SLR may depart from a strictly linear behavior. Similar findings were uncovered by (Bilskie et al. 2014), who suggest that the effects of SLC go beyond a simple change in base sea-level elevation. Such

---

[3] To address this recurring flooding issue, the City of Newport Beach has installed a combined total of 86 city tidal valves that need to be manually shutdown during the largest annual astronomical tides, referred to locally as "king tides". Source: City of Newport Beach, CA retrieved from http://www.newportbeachca.gov/index.aspx?page=1070; see also (Patrick J. Kiger 2012). The city of Olympia, WA is also implementing this solution during high tide events. Ref: City of Olympia, WA, retrieved from www.olympiawa.gov.

© ASCE 2014

coupling effects have been documented to affect tidal amplitudes on the West Coast, as evidenced by (Flick, Murray, and Ewing 2003).

Recommendation: Due to strong specificities in storm surge and SLC relationships, a site-specific assessment requiring statistical procedures (quantile regression; extreme value analysis; singular spectrum analysis (SSA); time series methods; and others) may be required during any RSLC study. For the same reason, a site-specific forecasting of hurricane and storm surge sensitivity to RSLC should be performed numerically, by using tools such as ADCIRC.

Wave Heights and Storminess

In their report, the National Research Council reports evidence that, on the West Coast, wave heights have increased from northern California to Washington during the past few decades. Climate models project ample winter storm activity in the North Pacific in future decades, suggesting that periods of anomalously high sea level[4] and high waves will continue to occur along the west coast (NRC 2012). Because West Coast storms are extra-tropical or combinations of extra-tropical storms with potentially long duration, the likelihood of stacking up high wave heights during a high tide is event is significant. Some global climate models project that the North Pacific storm track will shift northward as global climate warms during the next several decades, a process which would generate extreme wave heights and storm surges.

Recommendation: While some approximate quantification of wave height increase may be obtained from the aforementioned literature, a sensitivity study will be required to assess wave activity in response to changing mean sea level – such as STWAVE (Smith and Sherlock 2007)

ENSO and SLC

In addition to affecting waves, storm and hurricane activity and tidal cycles, variations in mean-sea levels can also be affected by large ocean phenomena, such as the The El Niño–Southern Oscillation (ENSO). The ENSO index serves to measure its intensity. Historical records indicate some correlation between strong El Nino events (positive ENSO indices) and marked increases in MSL. ENSO can also drive thermal expansion, resulting in some regional changes to sea levels. For example, At the Fort Point, San Francisco, CA, tidal gauge, NOAA CO-OPS services recorded a nearly 30 cm increase from the mean trend in 1984 and 1998, where the El Nino was strongest, as illustrated in Figure 3. Such observations add further weight to considering a large range of uncertainty when dealing with long-term sea-level projections for capital improvement strategies.

Recommendation: Advanced statistical methods, including unsteady multivariate extreme value analysis, SSA, spectral methods, may be deployed to assess the future sensitivity of mean sea level in response to strong ENSO events. Co-variate extreme value analysis methods have shown value in projecting intra-decadal RSLC values based on ENSO activity (Menendez, Mendez, and Losada 2009).

Morphological Changes and Sedimentation Processes

Sea level rise will cause coastal morphological changes due to increased wave and tidal forces and increasing scour conditions. Direct morphological consequences include new coastlines and

[4] In their paper, Moritz et al. (Moritz et al. 2013) show that infra-gravity effects can have significant impacts on nearshore water level; such phenomenon is expected to amplify in response to climate change and SLC.

beach profiles, modified sediment budget, littoral transport, and dune location. Ecological dynamics that shape the morphology will also be affected. Changing soil chemistry and drowning biological systems could result in a change in species composition or the migration of vegetation zones (Reed, Peterson, and Lezina 2006; Swanson et al. 2013). Salt marshes that had once acted as a buffer for storm surge would be forced to retreat inland or be drowned. Coastlines that experience subsidence will be the most vulnerable to this vertical accretion of marshland. Tidal freshwater ecosystems will likely be replaced by brackish marshes. Salt marshes will convert to areas of open water because the rate of vertical accretion will be low relative to that of brackish marshes (Craft et al. 2009), effectively changing the morphological dynamics of the coastal marshland environment.

Recommendation: Due to their complexity and ramifications, long-term morpho-dynamics should be discussed prior to the design phase of a project. Furthermore, the regional nature of this issue may require the involvement of a large number of stakeholders, which may be above the capabilities of those directly involved in the project. If a study is undertaken, it will usually involve specific numerical model packages capable of estimating long-term change to coastal profiles (GENESIS, ADH, etc.).

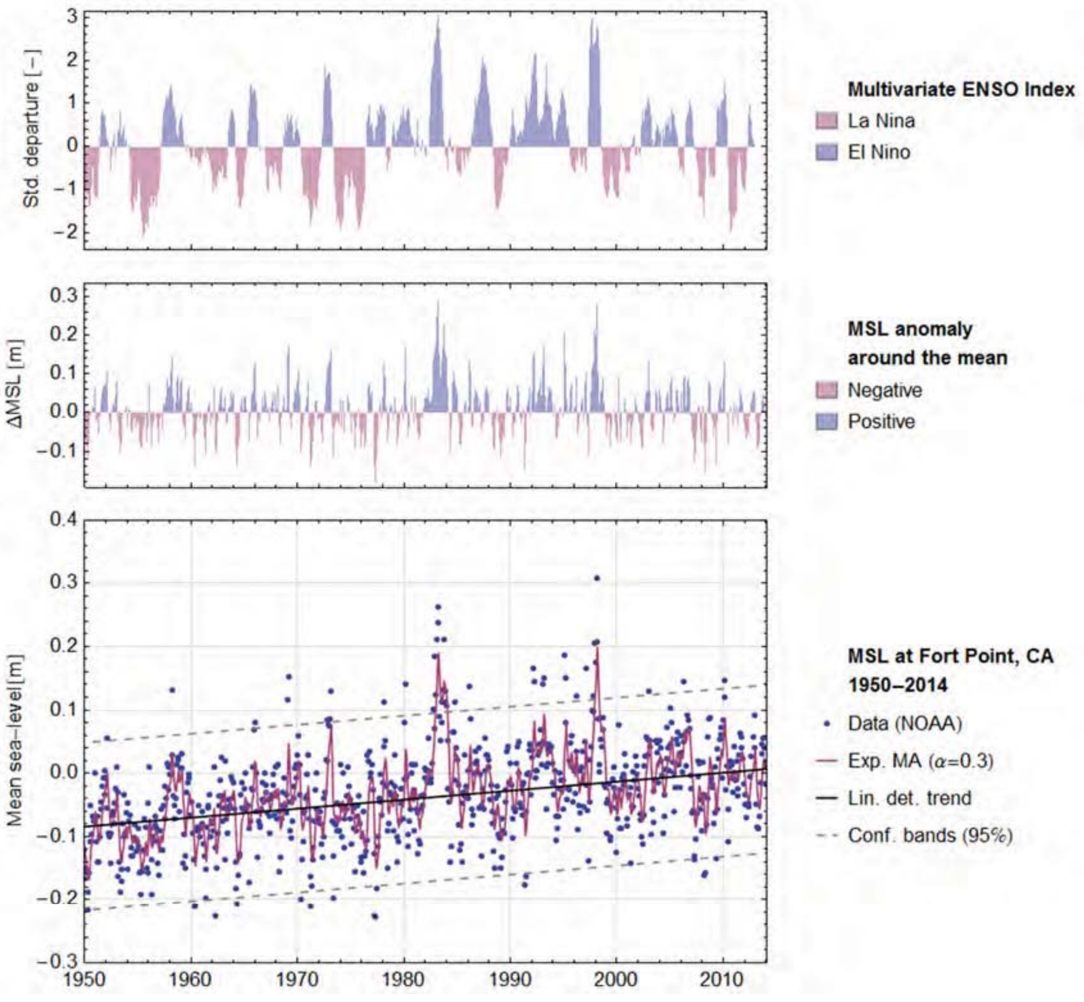


Figure 3. The figure provides visual evidence of the close relationship between measured variations in the overall energy level in the Pacific region through the MEI with measured mean sea level (MSL) at Fort Point, San

© ASCE 2014

Francisco, CA. This suggests that future increases in the MEI may in the future affect medium- to long-term trends in SLC. (**top**) Multivariate ENSO Index (MEI) standardized variations [source: NOAA ESRL]; (**center**) mean-sea level anomaly as measured deterministic mean trend, assumed to be a linear function of time at Fort Point, San Francisco, CA; (**bottom**) monthly MSL, in meters, referenced to the 1983-2001 Tidal Epoch MSL. Linear historical trend and exponential moving average are shown. [Source: NOAA CO-OPS station 9414290].

TOWARD RESILIENT MARINE CIVIL WORKS

The Value of Resilient Design

Designers and engineers of marine civil works must consider their client's needs and also those of the other stakeholders who depend on the project. Resilience, measured here as the capacity of a marine structure to quickly recover from a catastrophic event, benefits not just the owner/operator of the project itself, but also the public and private stakeholders with an interest in the long term functioning of marine civil works. Inadequately designed structures have far-reaching consequences[5], with direct, indirect, and intangible consequences that affect all of the stakeholders of that structure, as outlined in (A. Becker et al. 2013):

- **Direct damages** refer to damages that occur at the time of the weather event and are a direct result of it, such as damage to structures, marine civil works, and property.
- **Indirect costs** are the "reduction in production of goods and services, measured in terms of value added" (Hallegatte 2008). These include losses associated with the disaster that occur in the weeks, months, or years following the event. They also include losses or gains in wages, changes in profits, and decrease or increase in production.
- Finally, **intangible consequences** include many non-market consequences of disasters. Examples include: loss of life, health impacts, ecosystem damages, and damages to historical and cultural assets. These consequences of the disaster, sometimes called high-order losses (Rose 2004) or hidden costs (H. John Heinz III Center for Science 2000) are very difficult to characterize and quantify as there are often no direct economic measures.

Recommendations for creating a RSLC storyline

RSLC can have consequences including increased dredging costs, operations downtime, wave-induced structural degradation, flooding, and many others. In addition, some impacts will be compounded during episodic weather events, such as hurricanes and storm events. To capture this intricate ensemble of forcing, cost functions and constraints, this Committee suggests a "storyline" that is articulated around three key steps[6] outlined as follows.

- **Step 1**. Provide context to stakeholders
- **Step 2**. Survey, analyze and model local sea level change and other factors
- **Step 3**. Manage uncertainty and implement adaptive measures

The following sections describe each of these steps in more detail. These steps are iterative and do not necessarily flow in a neat linear fashion as outlined here.

Step 1. Provide context to stakeholders

[5] The IPCC (2012) defines impact as an umbrella term to capture both the direct damage to a given facility as well as the various indirect costs and intangible consequences (economic or otherwise) of that damage.
[6] While formulated slightly differently, these steps are similar in nature to those outlined in the 6-step Principles and Guidelines (P&G) approach described in (USACE 2000) and adopted by the Water Resources Council in 1983.

© ASCE 2014

Step 1 outlines the objectives, constraints, guidelines, and identifies the stakeholders involved in the project, which can include federal, state, and local authorities, public and private interests, the environment and others. This process informs decisions so that the "interested public and decision makers in the planning organization can be fully aware of: the basic assumptions employed; the data and information analyzed; the areas of risk and uncertainty; the reasons and rationales used; and the significant implications of each alternative plan" (USACE 2000). Here, a major difficulty involves establishing baseline RSLC projections, which may not be consistent across all authorities involved. Within the context of a single structure, the Designer should clearly articulate a rationale for establishing long-term RSLC projections. This includes defining a construction start date; end of design life; any provision for after design life has expired; criticality of the structure; ease of upgrading; stakeholders to be involved during any upgrade in response to changing climate conditions.

Step 2. Survey, analyze and forecast sea level change and other factors

Step 2 quantifies RSLC. It includes data collection (survey), analysis and sensitivity studies (forecast) if needed to inform Step 3. The survey, analysis and forecast of RSLC and other factors is critical to inform measure planning and selection. Based on the context established in Step 1, a range of RSLC projections should be reviewed and agreed up to provide mean global values for long-term RSLC, which may not match site-specific projections. To complement these generic values, stakeholders are encouraged to proactively conduct site-specific topographic (structure elevations), bathymetric (including trends in sediment transport) and hydrographic (water sensors) surveys, or rely on local data provided by others (e.g. NOAA, USGS, etc.). Modern data management systems, including Geographical Information System (GIS) or Building Information Model (BIM) offer efficient ways to manage the large amount of data thus collected. Based on these site-specific RSLC projections, the recommendations for actions to establish projected trends in wave climate, tidal fluctuations, storminess, storm surge, changes in coastal profiles, etc. can be implemented.

Step 3. Manage uncertainty and implement adaptive measures

Step 3 formulates alternative measures in response to RSLC; their evaluation and comparison; and the selection based upon that comparison. Depending on project criticality, requirements, and financing constraints, several approaches may be identified, selected and implemented. Measure implementation can be declined in three flavors including: (a) scheduled ("build today and proceed to upgrade in several steps"); (b) precautionary ("build today for long-term RSLC projections"); and (c) opportunistic ("build now with room for possible upgrades when funds become available") (DEFRA 2009).

Managing uncertainty

The designer or engineer may elect to base their choice on the acceptable probability of failure. The acceptable probability for an area being flooded depends on the size, the type and value of the project. Acceptable probability of failure is affected by availability of replacement facilities, economic condition, cultural importance, etc. For instance, low, medium and high scenarios

© ASCE 2014

currently suggested by the State of California (and others) and shown in Figure 4 may be interpreted as risk curves for non-critical, important and critical structures[7], respectively.

Selecting Measures

Due to the varied nature of possible hazards, there can be a diverse choice of measures (structural, non-structural, "green", etc.) available to the designer to address the impact of RSLC and other factors over the design life of the project. Options can be guided by owner budgets, tolerable risk, and service life. Strategies can generally be grouped into: minimum design, incremental improvements (adaptive management), and upfront defense. Similar terms are found in (DEFRA 2009), which lay out precautionary, scheduled and opportunistic approaches to climate change adaptation. Although the upfront costs are lowest with the minimum design, the cost at the end of the structure's service life could potentially be the highest. In addition, considerations should be made for the indirect costs and intangible consequences to non-owner stakeholders in the event of failure (Becker et al, In Press).

Due to the burden of paying upfront for features that will not be required for (potentially) several decades, the net residual cost of deferring improvements through adaptive management will often be the best value to the project and the owner. This may not be applicable to some features (such as deck height), but many features (such as the height of a seawall) can be designed for improvement later in the service life. Deferring the construction of some features for decades can result in a significant overall cost-benefit to the owner, particularly if the engineer designs for the improvements at the later date (World Bank 2009; Hinkel et al. 2014). In general, by incorporating early on elements of uncertainty, and by recognizing and evaluating the risk of a wide range of outcomes, adaptive management is likely to have a lower net residual cost to the project than a deterministic approach (Stern 2007).

Illustrations

To illustrate the general principles and methods outlined in this paper, two hypothetical examples are presented in Figure 5 below, for which a cursory review of factors to consider and sample adaptation measures are presented. Due to the generic nature of these examples, their specific context is not discussed.

Rubblemound Revetment

Rubblemound revetments, defined as layers of protection on the top of a sloped surface to protect the underlying soil against wave attack; they are often used along coastline to protect public assets such as highways, pathways, promontories, etc. (Douglass and Krolak 2008). RSLC may affect revetments by increasing overtopping volume, run-up height and scour intensity, wave height, frequency and magnitude of inundation and potential flooding. Concrete elements may deteriorate and rock armor may destabilize. Over time, the structure may fail.

---

[7] These terms are understood in a qualitative manner and are intended to communicate the acceptable level of failure: non-critical (high level of failure); important (average level of failure); critical (low level of failure).

© ASCE 2014

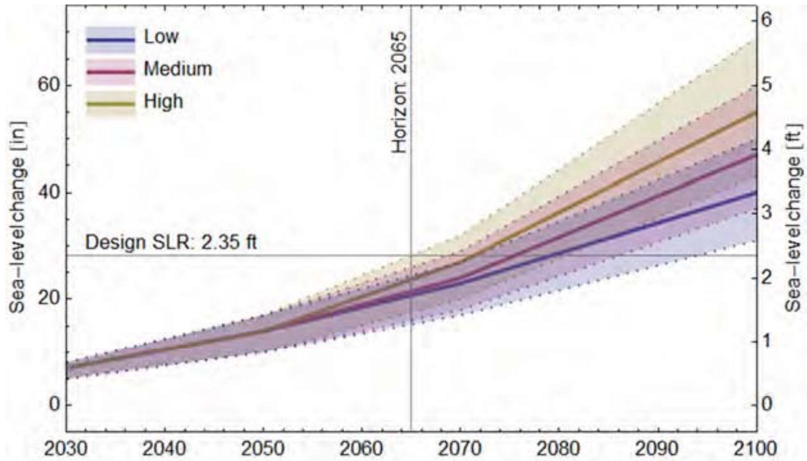


Figure 4. The low, medium and high trajectories suggested for planning of long-term trends for SLC by the State of California for use in coastal projects may be used to formulate an adaptation approach, which may be precautionary, scheduled, or opportunistic, as elegantly illustrated in (DEFRA 2009). Dates and values are for illustration purposes only.

A comprehensive study addressing wave height sensitivity, projected increases in storminess, hurricane activity, tidal cycles and sediment transport should be conducted. Because of the relative ease of upgrading the structure over time, a scheduled or opportunistic implementation approach may be selected.

Depending on the projected severity and timing of these forcing functions, a wide variety of structural adaptation measures may be implemented over time. If right of way restrictions do not apply, widen and increase the top berm width; place additional material to elevate crest height; install new cast-in-place element to provide additional freeboard during extreme storm events. Non-structural options may include hybrid/grass revetment (Pullen et al. 2007).

Case Study 2: Wharf

Wharves, defined as a vertical structure on the shore that extends out into the water, are common components of seaports and are used to moor ships to load/unload cargo. Higher water levels can cause more frequent flooding of the deck and impact mechanical, power generation and other equipment. Utilities should be located to accommodate the design water levels; those located underneath the deck of the wharf may be affected by more frequent flooding events and corrosion. Mooring loads may be sensitive to RSLC and varying wave climate. Hardware (including hoppers, Ship-to-Shore outlets, cranes, etc.) may be affected by changes in air gaps and clearances. Vaults and trenches also typically contain drains which could allow water to penetrate from below. With changes in the tidal and splash zone, possible structural weaknesses may stem from marine borers accessing higher points in the structure; and elevated moisture content of timber elements at higher elevations. Concrete and steel elements would be subject to increased corrosion.

Because of the difficulty in upgrading the port elevation, a higher risk curve may be elected to inform any measure implementation. Depending on the predicted design life of the structure and the sea level rise anticipated, it may be possible to select a deck elevation that meets current needs as well as allows for future sea level rise. However, for longer design lives and larger design values of sea level rise, this may not be possible or practical. Alternatives include designing for future installation of a curb around the perimeter of the structure. For longer periods, planning for a future retrofit to increase the height of the deck may be considered. This could consist of installing lightweight fill on the existing deck with a topping slab. In this case, the structure would need to be designed considering this future dead load and inertial mass. Other methods, such as jacking, may be cost prohibitive.

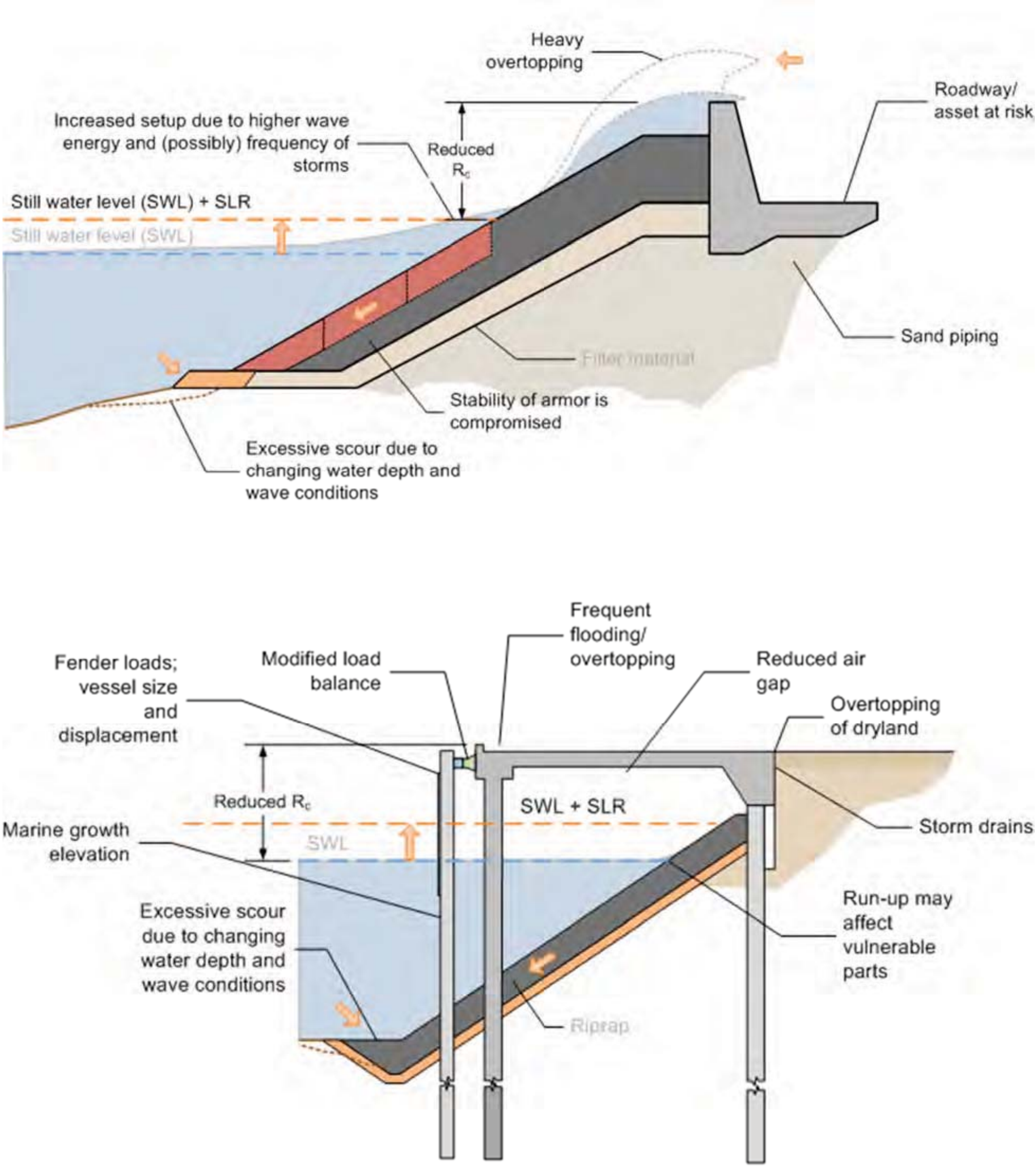


Figure 5. Effects of change in base-sea level on rubblemound breakwater (**top**) and wharf (**bottom**). In addition to a change in mean sea level, other factors combine to accelerate the degradation of hard structures in response to the accelerating degradation of climate conditions. Therefore, an engineer/owner response to RSLC

© ASCE 2014

should be site-specific, addressing localized challenges, service life and budgetary constraints while appropriately balancing risk and safety.

CONCLUSION

Both observation and calculated predictions indicate that sea level is rising globally. However, the change in sea level projected for a given location does not always correlate directly with global changes. The factors affecting sea level change at local site are vast and complex because it is not only sea level that is changing, but also the site itself. Calculating how each variable contributes to change at a given location is a difficult and potentially complex task. However, much can be done in terms of observation of trends and modeling in order to plan and design for the future. Local impacts are and will remain fundamental to planning and decision making for local marine civil works. The COPRI Committee has outlined several specific recommendations for quantifying RSLC, as well as some broad steps that should be undertaken in the early stages of project selection and design. As the Manual of Best Practices continues to develop, this COPRI Committee will continue its efforts to prepare, compile and publish general guidelines and design suggestions to assist engineers and designers in implementing a careful and well laid out approach to adapting design to accommodate sea level change for coastal and nearshore marine civil works.

ACKNOWLEDGEMENTS

The authors wish to thank the other members of the COPRI Committee and in particular Heidi Moritz and Jack Gerwick for their guidance, comments, and suggestions.

REFERENCES

A. Parris, P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, et al. 2012. "Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1."

Atkinson, John, Jane McKee Smith, and Christopher Bender. 2013. "Sea-Level Rise Effects on Storm Surge and Nearshore Waves on the Texas Coast: Influence of Landscape and Storm Characteristics." *Journal of Waterway, Port, Coastal, and Ocean Engineering* 139 (2): 98–117. doi:10.1061/(ASCE)WW.1943-5460.0000187.

Becker, Austin, Michele Acciaro, Regina Asariotis, Edgard Cabrera, Laurent Cretegny, Philippe Crist, Miguel Esteban, et al. 2013. "A Note on Climate Change Adaptation for Seaports: A Challenge for Global Ports, a Challenge for Global Society." *Climatic Change* 120 (4): 683–95.

Becker, A., P. Matson, and M. Fischer, *Toward Seaport Resilience for Climate Change Adaptation: Stakeholder Perceptions of Hurricane Impacts in Gulfport (MS) and Providence (RI).* Journal of Progress in Planning, In press.

Becker, Austin, Satoshi Inoue, Martin Fischer, and Ben Schwegler. 2011. "Climate Change Impacts on International Seaports: Knowledge, Perceptions, and Planning Efforts among Port Administrators." *Climatic Change* 110 (1-2): 5–29. doi:10.1007/s10584-011-0043-7.

Bilskie, M. V., S. C. Hagen, S. C. Medeiros, and D. L. Passeri. 2014. "Dynamics of Sea Level Rise and Coastal Flooding on a Changing Landscape: Coastal Flooding on a Changing

© ASCE 2014

Landscape." *Geophysical Research Letters*, January, n/a–n/a. doi:10.1002/2013GL058759.

Brundtland, Gro Harlem. 1987. "Brundtland Report. Our Common Future."

Craft, Christopher, Steve Pennings, Jonathan Clough, Richard Park, and Jeff Ehman. 2009. "SLR and Ecosystem Services: A Response to Kirwan and Guntenspergen." *Frontiers in Ecology and the Environment* 7 (3): 127–28.

DEFRA. 2009. "Appraisal of Flood and Coastal Erosion Risk Management. A Defra Policy Statement". London, UK: Department for Environment, Food and Rural Affairs. www.defra.gov.uk.

Douglass, Scott L., and Joe Krolak. 2008. "Highways in the Coastal Environment. Hydraulic Engineering Circular 25. Second Edition." Hydraulic Engineering Circular FHWA-NHI-07-096. Washington, D.C.: U.S. Department of Transportation; Federal Highway Administration.

Flick, Reinhard E, Joseph F Murray, and Lesley C Ewing. 2003. "Trends in United States Tidal Datum Statistics and Tide Range." *Journal of Waterway, Port, Coastal, and Ocean Engineering* 129 (4): 155–64.

Grinsted, Aslak, J. C. Moore, and S. Jevrejeva. 2009. "Reconstructing Sea Level from Paleo and Projected Temperatures 200 to 2100 Ad." *Climate Dynamics* 34 (4): 461–72. doi:10.1007/s00382-008-0507-2.

H. John Heinz III Center for Science. 2000. *The Hidden Costs of Coastal Hazards: Implications for Risk Assessment and Mitigation.* Island Press.

Hallegatte, Stéphane. 2008. "An Adaptive Regional Input-Output Model and Its Application to the Assessment of the Economic Cost of Katrina." *Risk Analysis* 28 (3): 779–99.

Heberger, Matthew, and others. 2009. "The Impacts of Sea-Level Rise on the California Coast". Pacific Institute.

Hinkel, J., D. Lincke, A. T. Vafeidis, M. Perrette, R. J. Nicholls, R. S. J. Tol, B. Marzeion, X. Fettweis, C. Ionescu, and A. Levermann. 2014. "Coastal Flood Damage and Adaptation Costs under 21st Century Sea-Level Rise." *Proceedings of the National Academy of Sciences* 111 (9): 3292–97. doi:10.1073/pnas.1222469111.

Hoffman, John Steven, Dale L Keyes, and James G Titus. 1983. *Projecting Future Sea Level Rise: Methodology, Estimates to the Year 2100, and Research Needs*. Strategic Studies Staff, Office of Policy Analysis, Office of Policy and Resource Management, US Environmental Protection Agency.

IPCC. 2001. *Climate Change 2001: Working Group I: The Scientific Basis*. Cambridge, UK; New York, NY: Cambridge University Press; University Press, New York. http://www.climatechange2013.org/images/uploads/WGI_AR5_SPM_brochure.pdf.

———. 2007. *Climate Change 2007 : The Physical Science Basis : Working Group I Contribution to the Fourth Assessment Report of the IPCC.* Cambridge: Cambridge University Press.

———. 2013. "Climate Change 2013. The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers". Intergovernmental Panel on Climate Change (IPCC). http://www.climatechange2013.org/images/uploads/WGI_AR5_SPM_brochure.pdf.

© ASCE 2014

Jevrejeva, S., J.C. Moore, and A. Grinsted. 2012. "Sea Level Projections to AD2500 with a New Generation of Climate Change Scenarios." *Global and Planetary Change* 80-81 (January): 14–20. doi:10.1016/j.gloplacha.2011.09.006.

Menendez, M., F. J. Mendez, and I. J. Losada. 2009. "Forecasting Seasonal to Interannual Variability in Extreme Sea Levels." *ICES Journal of Marine Science* 66 (7): 1490–96. doi:10.1093/icesjms/fsp095.

Moritz, Hans R, Ron Cox, Bill Peirson, James Carley, and Kathleen White. 2013. "Transient Effects of Storm-Induced Water Levels and Consequences for Coastal Vulnerability." In *Coasts and Ports 2013: 21st Australasian Coastal and Ocean Engineering Conference and the 14th Australasian Port and Harbour Conference*, 240. Engineers Australia.

NRC. 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. The National Academies Press. http://www.nap.edu/openbook.php?record_id=13389.

———. 2013. *Abrupt Impacts of Climate Change: Anticipating Surprises*. The National Academies Press. http://www.nap.edu/openbook.php?record_id=18373.

Oerlemans, Johannes. 1989. "A Projection of Future Sea Level." *Climatic Change* 15 (1-2): 151–74.

Patrick J. Kiger. 2012. "Knee-Deep in Doubt." *Orange Coast*, May.

Pullen, T., A. Kortenhaus, N.W.H. Allsop, T. Bruce, and H. Schuttrumpf. 2007. "EurOtop - Wave Overtopping of Sea Defences and Related Structures: Assessment Manual". EA Environment Agency, UK. ENW Expertise Netwerk Waterkeren, NL. KFKI Kuratorium für Forschung im Küsteningenieurwesen, DE.

Rahmstorf, Stefan. 2010. "A New View on Sea Level Rise." *Nature Reports Climate Change*, no. 1004 (April): 44–45. doi:10.1038/climate.2010.29.

Reed, Denise J, Mark S Peterson, and Brian J Lezina. 2006. "Reducing the Effects of Dredged Material Levees on Coastal Marsh Function: Sediment Deposition and Nekton Utilization." *Environmental Management* 37 (5): 671–85.

Revelle, Roger. 1983. "Probable Future Changes in Sea Level Resulting from Increased Atmospheric Carbon Dioxide." *Changing Climate*, 433–48.

Rose, Adam. 2004. "Economic Principles, Issues, and Research Priorities in Hazard Loss Estimation." In *Modeling Spatial and Economic Impacts of Disasters*, 13–36. Springer.

Ruggiero, Peter. 2013. "Is the Intensifying Wave Climate of the U.S. Pacific Northwest Increasing Flooding and Erosion Risk Faster Than Sea-Level Rise?" *Journal of Waterway, Port, Coastal, and Ocean Engineering* 139 (2): 88–97. doi:10.1061/(ASCE)WW.1943-5460.0000172.

Smith, Jane M, and AR Sherlock. 2007. "Full-Plane STWAVE with Bottom Friction: II. Model Overview." *System-Wide Water Resources Program Technical Note, Vicksburg, MS: US Army Engineer Research and Development Center.*

Stern, N. H. 2007. *The Economics of Climate Change: The Stern Review*. Cambridge, UK ; New York: Cambridge University Press.

Swanson, Kathleen M., Judith Z. Drexler, David H. Schoellhamer, Karen M. Thorne, Mike L. Casazza, Cory T. Overton, John C. Callaway, and John Y. Takekawa. 2013. "Wetland Accretion Rate Model of Ecosystem Resilience (WARMER) and Its Application to Habitat Sustainability for Endangered Species in the San Francisco Estuary." *Estuaries*

© ASCE 2014

and Coasts, September. doi:10.1007/s12237-013-9694-0. http://link.springer.com/10.1007/s12237-013-9694-0.

USACE. 2000. "Planning Guidance Notebook. ER 1105-2-100". Circular 1105-2-100. Washington, DC 20314-1000: U.S. Army Corps of Engineers.

———. 2011. "EC 1165-2-212 Water Resource Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs". Circular 1165-2-212. Washington, DC 20314-1000: U.S. Army Corps of Engineers.

World Bank. 2009. "The Costs to Developing Countries of Adapting to Climate Change: New Methods and Estimates, Consultation Draft". World Bank.

© ASCE 2014

Indicator-based vulnerability screening for improving infrastructure resilience to climate change risks

Christopher Evans[1], Angela Wong[2], Cassandra Snow[2], Anne Choate[2], Beth Rodehorst[3]

[1] ICF International, 222 Somerset Street West, Ottawa, ON K2P 2G3, Canada; PH (613) 520-1824; FAX (613) 523-0717; email: Christopher.Evans@icfi.com
[2] ICF International, 1725 I St. NW, Washington D.C., 20006; PH (202) 862-1200; FAX (202) 862-1144
[3] ICF International, 615 SW Alder Street, Portland, OR 97205; PH (415) 677-7146; FAX (415) 677-7177

Abstract

To understand and manage risks from climate change and extreme weather, infrastructure designers, owners, and operators need to know where vulnerabilities exist in the system, including how asset-specific vulnerabilities relate to system-wide vulnerabilities. This is harder than it seems: practitioners are faced with several barriers to effectively assess vulnerability, including the resources and time required for detailed studies, limitations in climate and asset information, and challenges in translating climate information at an appropriate level of detail to inform investment, design, and maintenance decisions. This paper presents an indicator-based vulnerability screening approach and discusses practical steps for data collection, scoring and weighting, and validation of results. The benefits of this approach are that it leverages existing information on climate and assets to save time and cost, and relies on metrics that can be applied as part of benchmarking, performance measurement and evaluation, risk assessment, asset management, and prioritization strategies. Moreover, the paper discusses efforts underway to leverage this approach, applications for mainstreaming climate change considerations in infrastructure decision-making in developing and developed nations, and limitations of this approach that are ripe for further research.

Introduction

Extreme weather has disrupted critical infrastructure systems ranging from transportation networks to electrical grids. Infrastructure and services may face greater risks from climate change and extreme weather in the future—both from gradual changes from historical climate averages and more frequent or intense extreme weather. To understand climate risk, infrastructure providers need to know where the greatest vulnerabilities lie in a system. A successful climate vulnerability assessment is an important step that builds stakeholder awareness and relationships, illuminates interdependencies, drives data collection, and establishes priorities—all of which are needed to effectively manage climate risks to infrastructure services.

© ASCE 2014

Infrastructure providers, however, face barriers in carrying out effective vulnerability assessments. First, detailed assessments require a lot of resources, time, and expertise. Second, climate and asset data collection processes can be onerous alongside daily operational needs—and even when data are available, translating climate information into metrics that are relevant to engineers often requires third-party guidance and expertise. Downscaling climate projections to the resolution required for project-level design decisions is expensive and challenging, and magnifies uncertainties. Further, readily available downscaled data are presented in units that are often incompatible with engineering design processes and guidance (e.g., average seasonal temperature, average annual precipitation). If not carefully managed, the process can leave participants scratching their heads, trying to determine how to use the results to direct scarce resources in day-to-day and longer-term decisions.

Indicator-based screening approaches can help address many of these barriers. A vulnerability screening assessment is designed to efficiently identify assets that are likely to be most vulnerable to climate risks and have the potential to contribute to system-wide vulnerabilities. An indicator-based screening approach draws on readily available information: coupling *existing* information on climate with *existing* information about assets solicited from infrastructure managers to develop vulnerability scores. These scores are based on indicators that can be integrated into existing decision-making processes; for example, indicator-based screening can inform planning, design, infrastructure asset management, risk management, emergency response planning, and long-term capital investment decisions. This approach focuses resources on areas that warrant further investigation and analysis. . Indicator-based screening is cost-effective and time-efficient, both in the effort required for data collection, and in helping practitioners determine how to direct scare engineering resources for more detailed analysis and risk mitigation efforts. In addition, this screening enables practitioners to explore climate risk assessments incrementally, gaining buy-in and acceptance from key stakeholders.

This paper presents an approach to indicator-based assessment and discusses practical steps for data collection, scoring and weighting, and validation of results. Moreover, the paper discusses efforts underway to apply this approach and use it to incorporate (or "mainstream") climate change considerations in infrastructure decision-making in developing nations, and limitations of this approach that are ripe for further research.

Overview of vulnerability assessment and an indicator-based approach

Vulnerability assessments identify the climate stressors, impacts, and assets of concern to inform effective adaptation and risk management responses. Vulnerability is a function of exposure, sensitivity, and adaptive capacity, as shown in Figure 1:

- Exposure is the nature and degree to which a system is exposed to climate change and extreme weather. Infrastructure projects are often particularly exposed to future changes in climate because they often are composed of long-lived assets that will be in place for many decades.

© ASCE 2014

- Sensitivity describes the relationship between a climate stressor, such as extreme heat or storms, and the ability of the asset or service to withstand associated impacts.
- Adaptive capacity refers to the ability of a system to respond successfully to climate change and extreme weather—in other words, how quickly can the system respond to avoid or minimize negative consequences when infrastructure services are disrupted by a climate impact?

Effective climate risk management strategies seek to limit infrastructure exposure, reduce sensitivity, and increase adaptive capacity. Infrastructure systems and services can be composed of numerous assets that can be vulnerable to a range of climate hazards across time.

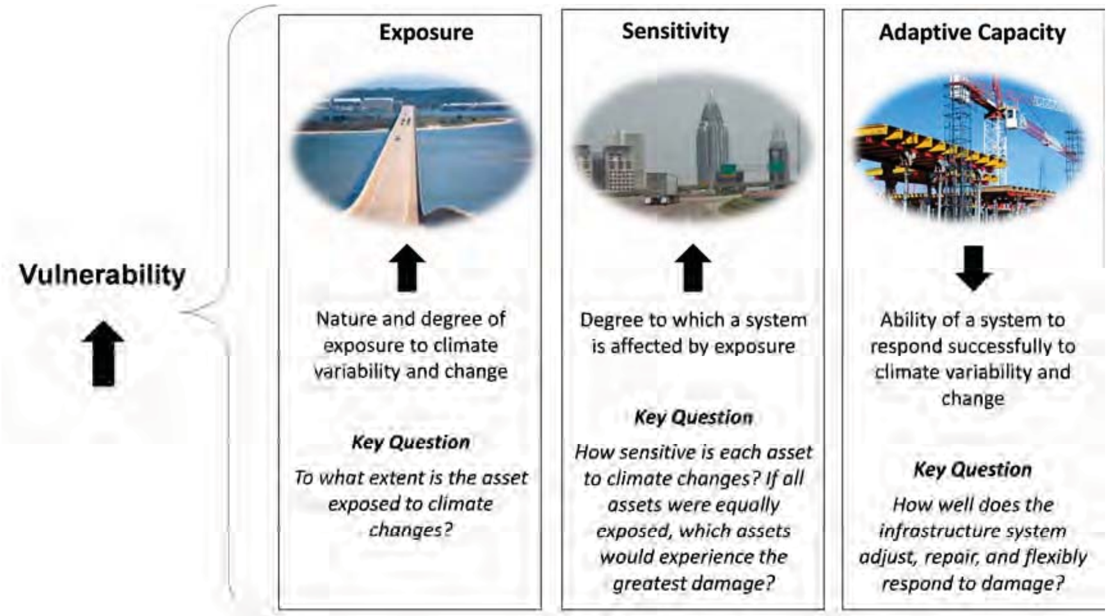


Figure 1: The three components of vulnerability: exposure, sensitivity, and adaptive capacity.

System vulnerability is a combination of top-down vulnerability assessment and bottom up, asset-specific vulnerability assessment to determine the critical components necessary to maintain a given level of service or performance, with consideration of adaptive capacity and redundancy factors that reflect the system's ability to bounce back or compensate for asset-specific vulnerabilities. In practice, the three components of vulnerability can be abstract and difficult to apply to infrastructure assets—using indicators to describe these components can help break down their complexity into manageable criteria.

An indicator is a representative data element that can be used to evaluate individual aspects of exposure, sensitivity, and adaptive capacity in a larger and more complex system. For example: road paving materials vary in their sensitivity to temperature, so looking at the types of paving materials used in roads and highways within a study

© ASCE 2014

area can provide an indication of how sensitive individual segments may be, given a certain level of exposure to high temperatures and changes in temperature extremes.

Instead of asking "what level of climate impacts is a road network exposed, sensitive, and unable to quickly bounce back from?", assessment questions become more detailed and specific to the types of information that infrastructure providers may have at-hand; for example:

- Which road segments are located in a 50-year flood zone?
- What height of storm surge would an asset experience in a 50-year hurricane event?
- Which segments would experience an increase in the number of days above the temperature threshold at which the pavement binder may soften?
- What are the detour routes available and how long does it take for an impacted segment to be brought back into service?

When applied within vulnerability screening, indicators can help define specific information needs, add depth and detail to assessments, and increase consistency. A generalized approach for incorporating indicators into vulnerability screening assessments includes the following steps:

1. Indicator identification
2. Scoring and weighting indicators
3. Validation and interpretation of results

This approach draws on the authors' experience with piloting indicator-based vulnerability screening methods on transportation studies including the U.S. Department of Transportation-funded (DOT) Gulf Coast Study, Phase 2 (DOT 2013a, 2013b) to assess vulnerability of transportation assets in all modes (e.g., highway, airport, rail, port, bus transit, and pipeline), and the Federal Land Management Agency's (FLMA) Southeast Region Transportation and Climate Change study (Rowan et al., 2014). These efforts have yielded practical tools and resources that can support implementation of an indicator-based approach to vulnerability screening.

Applying an indicator-based vulnerability screening approach to infrastructure systems

Indicator identification

The first step in an indicator-based approach involves identification and selection of indicators that can be used to assess the three components of vulnerability: exposure, sensitivity, and adaptive capacity. Indicators are most useful when they allow practitioners to distinguish differences in vulnerability among assets, are supported by existing datasets that are already tracked by infrastructure providers, and are transparent and easy to understand by the stakeholders involved in their assessment.

© ASCE 2014

The Gulf Coast Study Phase 2 and FLMA Southeast Region Transportation and Climate Change studies have made advances in indicator identification. For DOT, we have supported development of two tools to identify indicators for transportation assets: the Sensitivity Matrix and Sensitivity Screen, an Excel-based spreadsheet, that document the sensitivities of six transportation modes to major climate variables (DOT 2013a, 2013b; Rowan et al., 2013), and a Vulnerability Assessment Scoring Tool that is capable of screening a large number of transportation assets to climate impacts (Rowan et al., 2014). These tools relied on the following primary sources of data for indicator identification:

1. Expert consultations (i.e., with designers, managers, and operators of the infrastructure system)
2. Design standards
3. "Historical analogues," or historical case studies of climate impacts chosen for their similarity to projected climate scenarios
4. Asset management systems and databases
5. Spatial analysis

Additionally, identifying thresholds above which infrastructure systems are likely to exhibit sensitivity to climate impacts can both help inform indicator selection and be used in assigning scores for sensitivity. For example, transportation providers have identified that coastal bridges are much more susceptible to damage from storm surge when the surge reaches the height of the low-chord bridge elevation (DOT 2012). Given the knowledge of this threshold, the low-chord bridge elevation height is an appropriate indicator for sensitivity and can be scored against the specific storm surge elevations evaluated in the vulnerability analysis. Together, indicators and thresholds can add detail to screening-level assessments and help relate both short-term weather forecasts and longer-term climate projections to metrics that are directly relevant to decisions about the design, management, operation, or maintenance of infrastructure systems.

As vulnerability indicators are identified, they can be catalogued and referenced for future studies or to inform assessments across different sectors of infrastructure. The Gulf Coast Study Phase 2 and FLMA study teams have developed a list of indicators, or an "indicator library" that represents a starting point for research into low cost, highly accessible methods of evaluating the climate vulnerability of transportation assets (Rowan et al., 2014). An excerpt of indicators for assessing the sensitivity of bridge and highway assets to climate impacts is provided in Figure 2.

Sensitivity Indicator	Climate Impact
High volumes of truck traffic	①
Pavement binder type relative to projected temperatures	①
Whether pavement has rutted (or shown other signs of damage) in the past due to high temperatures	①
Whether an asset has been damaged by flooding in the past due to heavy rain	②
Asset's elevation relative to surrounding areas	②
Amount of impervious surface surrounding an asset	②
Elevation of the approach to a bridge	②③⑥
Age of an asset	②⑥
Asset condition	②③⑤⑥
Whether a bridge is "scour critical"	②⑥
Frequency that water overtops a bridge	②
Whether asset is paved	②⑥
Remaining Service Life (RSL) of asset	②④⑥
Whether an asset has been damaged in the past due to storm surge	⑥
Whether an asset is protected from flooding	③⑥
Bridge height	③⑥
Distance between water surface and bridge deck	⑥
Whether bridge is movable	⑥
Whether an asset has flooded in the past due to tidal events	③
Navigational clearance of a bridge	③
Density of roadway signals	⑤
Design wind speed of asset	⑤
Sensitivity of asset material to fire	④

Legend:

①	Heat	④	Wildfire	⑤	Wind
②	Heavy rainfall	③	Sea level rise	⑥	Storm surge

Figure 2: Excerpts from an indicator library for assessing the sensitivity of bridge and highway assets to climate impacts (Rowan et al., 2014).

Scoring and weighting indicators

Vulnerability screening approaches often use a system for "scoring" the vulnerability of individual assets or services to facilitate ranking of priorities and evaluate results across a large number of elements within an infrastructure system. This involves developing a scale for consistently scoring assets, whether by categories (e.g., "high", "medium", and "low") or numerical values (e.g., a five-point scale from lowest to highest).

Since indicators track representative elements of vulnerability, it is necessary to combine indicator scores to develop aggregated scores for exposure, sensitivity, and adaptive capacity. To score vulnerability indicators in the Gulf Coast Phase 2 Study, indicators were grouped into "bins" that were weighted to develop a weighted-average score for each component of vulnerability (i.e., exposure, sensitivity, and

© ASCE 2014

adaptive capacity). Each component was then weighted to develop an overall vulnerability score for each asset.

Figure 3 shows an example of this scoring process for a road segment; the segment is assessed on a four-point scale using indicators such as the projected change in days above 95°F, truck traffic density on the segment, and the length of detour necessary if service along the segment is disrupted by climate impacts (shown in each of the bars in Figure 3). These indicator scores feed into exposure, sensitivity, and adaptive capacity scores (shown in the pie chart) that are subsequently combined into a single vulnerability score (Rowan et al. 2014).

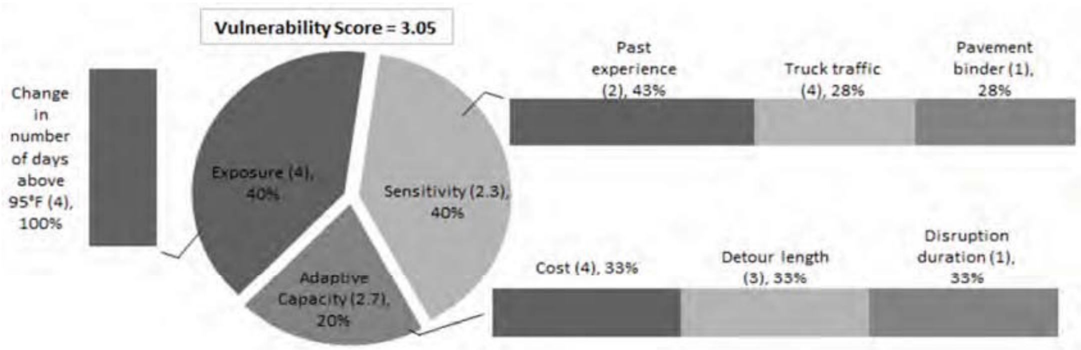


Figure 3: A four-point scoring system for indicators, grouped into weighted "bins" (shown as bars) to assess exposure, sensitivity, and adaptive capacity (shown in the pie chart), and aggregated to score overall vulnerability for a particular asset or infrastructure system component; scoring is shown in brackets and the percentages show the weighting of each indicator and vulnerability component (Rowan et al., 2014).

Validation of results

Validation ensures the results of a screening assessment are robust enough to inform decisions at the required level of detail. For example, if the results are greatly influenced by making adjustments in the weighting of indicators or vulnerability components, then it may not be possible to confidently identify the most vulnerable asset in a system, although it may still be possible to identify the top five or top ten.

In the Gulf Coast Study Phase 2, several validation measures were used to evaluate the robustness of results from a vulnerability screening of transportation assets in the Mobile, Alabama study area:

1. Sensitivity analyses, which investigated how the vulnerability rankings of transportation assets were affected by: excluding individual indicators; changing the weighting of exposure, sensitivity, and adaptive capacity components in calculating overall vulnerability; and decisions about grouping related indicators into categories.
2. A data completeness check, which tracked the extent to which data were available for a given indicator across the assets screened in the assessment.

© ASCE 2014

3. Peer review and "gut" tests to ensure results are consistent with the current and historic performance of assets, or that unexpected outcomes are supported by how assets may perform under projected changes in future climate conditions.

For example, Figure 4 shows the results of a sensitivity analysis on indicators used to assess the vulnerability of several road segments to extreme temperatures. The original vulnerability score for each segment is compared against the score when each individual indicator is excluded. This shows which indicators have the greatest effect on the vulnerability score, and how sensitive the overall score for each asset is to changes in the selected indicators.

Segment ID	Type	Original	External Trip Productions, Trucks (2007)	Average Daily Truck Traffic	Pavement Binder Type	Historical Performance
R1	Road	2.5	2.2	2.5	2.7	2.8
R2	Road	2.5	2.2	2.5	2.7	2.8
R2	Culvert	2.7	2.7	2.3	2.8	2.9
R2	Bridge	2.6	2.6	2.3	2.8	2.9
R2	Culvert	2.4	2.4	2.3	2.4	2.5
R3	Road	2.5	2.2	2.5	2.7	2.8
R3	Bridge	2.7	2.7	2.3	2.8	2.9

Figure 4: A sensitivity analysis of how vulnerability scores for a series of road segments change compared to an "original" score when each individual indicator is excluded; green denotes low vulnerability and red denotes higher vulnerability (DOT 2013b).

Discussion: Current work to extend indicator-based approaches and applications to developing nations

Mainstreaming climate change considerations into infrastructure decision-making in developing nations

The benefits of indicator-based screening for infrastructure vulnerability are highly relevant in developing countries. In particular, screening can help identify high-priority infrastructure vulnerabilities quickly, conserving scarce resources for the implementation of fast and effective responses.

Infrastructure providers in countries with critical development challenges, however, face an acute combination of stressors and barriers. These include: rapid growth in urban areas where infrastructure needs are highest, multiple development stresses (e.g., poverty, crime, and public health issues), high vulnerability to current climate variability and extreme events, limited technical capacity, scarce resources to assess vulnerability and implement adaptation strategies, limited data on future climate changes and the condition and performance of infrastructure, and varying levels of sophistication in planning and analysis tools.

© ASCE 2014

Foreign aid agencies and development banks are developing approaches for ensuring that infrastructure investments in developing countries are resilient to risks from climate change and extreme weather. The U.S. Agency for International Development (USAID) Climate Change Resilient Development (CCRD) project has developed a Climate Resilient Development Framework that focuses on a "development-first" approach, which aims to incorporate, or "mainstream", climate considerations into existing planning and decision-making processes. (USAID 2014)

As part of the CCRD project, the Climate Resilient Infrastructure Services (CRIS) program is working in five cities in developing countries to develop and test innovative approaches to integrate climate risk management into infrastructure decision-making. In Piura, Peru, CRIS has worked with city officials to implement the Climate Resilient Development Framework and develop a vulnerability screening approach for infrastructure projects and municipal services. This work has yielded several insights in applying climate vulnerability screening and indicator-based approaches in developing countries.

First, assessments must be informed by the local development context—the goals, objectives, barriers, climate and non-climate stressors, needs and opportunities. It is important to define the specific decision points that the vulnerability assessment will inform as an assessment method is selected. For example, in Piura, CRIS worked with officials to identify four decision-making responsibilities for infrastructure that required climate vulnerability information: (i) screening planned infrastructure projects at a pre-investment stage to identify potential climate risks; (ii) drafting Terms of Reference for technical consultants involved in the formulation, evaluation, and execution of investment projects; (iii) permitting private infrastructure investments, and (iv) managing city operations related to waste management and parks and landscaping.

Second, the "formal" application of indicators is often not possible, as information may not be consistently available on the condition or performance of assets. Instead, framing indicators as questions helps infrastructure providers to think practically about vulnerability. For example, a municipality may not have complete information on the capacity and condition rating of culverts they own or operate, but asking "where and why are culverts overwhelmed during heavy downpours?" can yield very specific information that can be incorporated into asset screening. Spatial analyses, such as hazard maps and urban development maps, are central planning tools that can inform indicators (e.g., is the asset located in a 50-year flood zone?), although the quality and format of these resources may differ; for example, paper-based maps may only be available rather than GIS shapefiles.

Third, infrastructure providers require support in incorporating information on future climate change into assessments. This is not unique to developing countries, but the barriers that providers face in identifying robust climate information at the right level of detail are more acute. Identifying thresholds at which climate impacts become more severe can help inform practical decision-making. For example, stakeholders in

© ASCE 2014

Piura generally understand the intensity and duration at which heavy downpours will cause serious flooding in the city; framing extreme precipitation projections relative to that threshold can help them interpret the information and make judgments on how changes may impact their planning and operations. Providing guidance on what robust climate information looks like, best practices, and principles for working with climate information is as useful to infrastructure providers as climate information itself; it gives decision-makers the conceptual tools necessary to work with local technical experts and consultants to maintain access to the most current and relevant climate information over the long term.

Engineering vulnerability assessments

Vulnerability assessments are only as useful as the actions that they inform to reduce vulnerability, manage risk, and improve the long-term sustainability and resilience of infrastructure services. There is an urgent need to move from assessment to action. Once they have identified high-priority vulnerabilities, infrastructure providers are faced with a challenging question: "now what?"

There is currently a lack of nationally-applicable standards of practice on how to account for climate change in both project-level asset design and system-level planning. This void makes it a huge leap to move from vulnerability assessment to practical action. In the transportation sector, the authors, along with engineering partners[1], are taking the next step through work with FHWA to extend results from the Gulf Coast Study, Phase 2 and address key barriers in adaptation decision-making, including:

- Addressing gaps in translating climate science into information that is applicable to detailed project-level design and specifications;
- Identifying promising asset candidates for detailed engineering assessment that can inform adaptation strategies across a wide range of climate stressors, infrastructure types, and geographies; and
- Developing recommended project-level practices, protocols, and methodologies to incorporate climate change risks into short- and long-term engineering solutions.

The indicator-based approaches we have piloted will directly inform these solutions. Indicators point to specific asset design elements that are influenced by environmental factors and how thresholds or performance criteria for these design elements are articulated in engineering specifications. This provides a starting point for detailed analysis of specific assets to understand their existing level of service, state of repair, and performance limits in the critical areas that are influenced by climate change and extreme weather. By incorporating scenarios of possible climate conditions at an appropriate level of detail to understand performance gaps,

[1] Parsons Brinckerhoff (PB) and South Coast Engineers

© ASCE 2014

adaptation measures can be identified and assessed for economic benefits as well as other considerations.

Other potential applications: benchmarking and performance measurement, asset management, risk assessments, and prioritization

The indicator-based approaches we have piloted draw upon existing experience, information, and decision-making processes to identify indicators and collect the data needed to evaluate them. As a result, the vulnerability screening results are often closely linked with existing processes, including methods for benchmarking and measuring the performance of infrastructure services. For example, indicators of infrastructure condition (e.g., bridge scour ratings, condition ratings, and maintenance intervals) and adaptive capacity (e.g., response time, time to resume full service level following a disruption, repair costs) are very relevant—and may, in fact be informed by—Key Performance Indicators for tracking the performance of infrastructure services and benchmarking against other assets. As measures to adapt to climate impacts and climate change are adopted over time, infrastructure managers may be able to use these indicators to track progress and performance improvements from adaptation strategies relative to baseline conditions.

As sectors adopt infrastructure asset management as a best practice—most notably in transportation—indicator-based risk screening approaches may offer an effective conduit between asset management plans and data collection systems and climate risk management efforts. Strong asset management systems underpin effective vulnerability and risk assessments while vulnerability assessment and extreme weather risk management efforts can inform transportation asset management: both support resilient decision-making (ICF 2014, TRB 2014). These synergies are evolving rapidly as state DOTs engage in both areas.

Indicator-based vulnerability screening also has applications for infrastructure risk assessment, and for prioritizing projects or management strategies to reduce risk. Risk assessment differs from vulnerability screening in that it incorporates information on the likelihood of a hazard occurring, and the consequence of its occurrence. Both exposure and sensitivity indicators (e.g., what level of storm surge is the asset exposed to in a 100-year event?; what aspects of an assets design or materials are subject to damage or failure given a certain level of exposure?) can inform assessments of both likelihood and consequence; adaptive capacity indicators such as response time, availability of detours or back-up systems, and repair costs can provide useful information on the consequences of impacts. And by linking practical features of infrastructure location, design, operation, and maintenance to climate information, indicator-based approaches can help support the integration of probabilistic information needed to assess risk. The outcome of this is a better sense of how to prioritize investments, effort, and further analysis to focus on the most critical risks to an infrastructure system.

© ASCE 2014

Limitations and Areas for Future Research

Moving from assessment to action is just one of the promising areas or further work needed to address challenges that infrastructure providers face. In adopting indicator-based approaches for vulnerability assessment and adaptation planning, decision-makers need to be aware of the following challenges and areas for further work:

- Indicator-based approaches draw heavily on historical experience, extrapolating from past impacts from climate variability and extreme events to understand how climate may change in the future. Practitioners need to consider possible future impacts that lie outside the realm of past experience, such as impacts that result from interaction between multiple climate and non-climate stressors. For example, how might strain on municipal services from rapid growth in urban areas interact with gradual increases in temperature *and* an increased frequency for intense downpours or coastal flooding from storm events?
- Indicator-based approaches are applicable to various sectors and climate impacts, but indicators themselves are often specific to particular sectors or climate impacts and geographies (e.g., coastal or riverine). Further work in this area could identify indicators across different types of infrastructure, climate impacts, and geographic areas, and share these results in "indicator libraries" similar to those developed through the Gulf Coast Study Phase 2 and FLMA work to date (see Figure 2).
- More research is needed to develop indicator approaches that capture the "cascading" system-level effects of disruption among multiple infrastructure services. For example, how might disruption of one infrastructure sector – such as electricity – have impacts on other essential infrastructure services – such as potable water delivery? Understanding these interactions can help inform the assessment of the relative criticality of various assets and facilities.
- Very little analysis has been done to investigate the relative importance or efficacy of indicators for different types of infrastructure and climate impacts. Future work could focus on testing the efficacy of indicators and to better-understand how they can be best applied to different local contexts, including in developing countries that face critical infrastructure challenges.

Conclusions

The results of the data-driven vulnerability screen provide infrastructure practitioners with a relatively low-cost starting point for understanding and managing their system's climate vulnerabilities. The outputs of the screen may help identify weak points in the infrastructure system, understand factors of vulnerabilities, and understand how likely it is that the system will be damaged by a stressor and how likely it can adapt. Through scoring and prioritizing vulnerability, the screening approach can help practitioners identify the most appropriate places to focus scarce resources for detailed analysis, including engineering assessments, cost-benefit analyses, and adaptation strategies.

© ASCE 2014

The indicator-based approach can be used in combination with stakeholder engagement as a starting point for adaptation planning and for raising awareness of vulnerability within or across organizations. Implementing this approach in the DOT's Gulf Coast Study Phase 2 and USAID's CRIS program has shown that the *process* of screening can be as valuable as the results by developing an improved understanding of the links between infrastructure management and climate change, and identifying how climate change considerations can be incorporated into existing decision-making activities.

There are significant opportunities to expand indicator-based vulnerability screening methods to a broad range of infrastructure sectors; indicators identified through these processes can equally inform infrastructure benchmarking and performance measurement, risk assessment, and prioritization of decision-making. Our experience has shown that this approach can yield practical, first-order information to managers at relatively low cost and effort in both developed- and developing-world contexts.

References

DOT. (2013a). The Gulf Coast Study, Phase 2—Task 2.4: Assessing the Sensitivity of Transportation Assets to Climate Change in Mobile, Alabama. U.S. Department of Transportation (DOT). Retrieved from http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task2/sensitivity_report/sensitivity_report_sept_2012.pdf

DOT. (2013b). The Gulf Coast Study, Phase 2—Task 3.1: Screening for Vulnerability. U.S. Department of Transportation (DOT). *In press.*

ICF. (2014). Leveraging Entry Points in the Transportation Asset Management Framework to Facilitate Integration of Extreme Weather Risk. Presentation by Anne Choate at the Transportation Research Board's 10th National Conference on Transportation Asset Management, Miami, Florida, April 28-30, 2014.

Rowan, E., Evans, C., Riley-Gilbert, M., Hyman, R., Kafalenos, R., Beucler, B., Rodehorst, B., Choate, A., Schultz, P. (2013). Assessing the Sensitivity of Transportation Assets to Extreme Weather Events and Climate Change. Transportation Research Record: Journal of the Transportation Research Board, 2326(-1), 16–23. doi:10.3141/2326-03

Rowan, E., Snow, C., Choate, A., Rodehorst, B., Asam, S., Hyman, R., Kafalenos, R., Gye, A. (2014). Assessing the Vulnerability of Transportation Infrastructure to Climate Change Using Indicators. Presented at the Transportation Research Board 93rd Annual Meeting. Retrieved from http://trid.trb.org/view.aspx?id=1289985 on July 7 2014.

© ASCE 2014

TRB. (2014). 10th National Conference on Transportation Asset Management. Transportation Research Board (TRB), Miami, Florida, April 28-30, 2014.

USAID. (2014). Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change. U.S. Agency for International Development (USAID), Washington, D.C. Retrieved from https://dec.usaid.gov/dec/GetDoc.axd?ctID=ODVhZjk4NWQtM2YyMi00YjRmLTkxNjktZTcxMjM2NDBmY2Uy&rID=MzQ1ODA3&pID=NTYw&attchmnt=VHJ1ZQ==&uSesDM=False&rIdx=NDQ3ODMz&rCFU= on July 7 2014.

© ASCE 2014

Adapting Infrastructure Practices to Climate Change

J. Rolf Olsen,[1] Bilal M. Ayyub,[2] Ted S. Vinson[3] and Richard N. Wright[4]

ABSTRACT

The climate science community informs us that extremes of climate and weather are changing from historical values and that the changes are driven substantially by emissions of greenhouse gases caused by human activities. Civil infrastructure systems traditionally have been designed, constructed, operated and maintained for appropriate probabilities of functionality, durability and safety while exposed to climate and weather extremes during their full service lives. Because of uncertainties in future greenhouse gas emissions and in the models for future climate and weather extremes, neither the climate science community nor the engineering community presently can define the statistics of future climate and weather extremes. This paper describes the knowledge available to the civil engineering community, suggests practical approaches for dealing with these uncertainties for current projects, and recommends cooperative research with the climate and social science communities to obtain improved bases for future civil engineering standards and practices.

[1] Senior Lead for Climate, Institute for Water Resources, U.S. Army Corps of Engineers (USACE), 7701 Telegraph Road., Alexandria, VA 22315, j.rolf.olsen@usace.army.mil

[2] Professor of Civil and Environmental Engineering, 305 Glenn L. Martin Hall, University of Maryland, College Park, MD 20742, ba@umd.edu

[3] Professor (Emeritus) of Civil and Environmental Engineering, Oregon State University, 11029 Dublin Canyon Road, Pleasanton, CA 94585, teds.vinson@gmail.com

[4] Retired Director, Building and Fire Research Laboratory, National Institute of Standards and Technology, 20081 Doolittle Street, Montgomery Village, MD 20886, richard.n.wright@verizon.net

© ASCE 2014

1. INTRODUCTION

The purpose of the ASCE Committee on Adaptation to a Changing Climate (CACC) is to identify and communicate the technical requirements and civil engineering challenges for adaptation to climate change. Based on its work, activities may be planned in the constituent committees of the Committee on Technical Advancement, the Institutes, and other elements of ASCE. These activities may result in recommendations for initiatives related to:

- Climate change and its effect on the safety, health and welfare of the public as it interfaces with civil engineering infrastructure.
- Appropriate standards, loading criteria, and evaluation and design procedures for the built and natural environment, and related research and monitoring needs.

This paper is derived from a report of CACC (Olsen, et al. 2014) entitled *Bridging the Gap between Climate Science and Civil Engineering Practice;* its purpose is to:

- Foster understanding and transparency of analytical methods necessary to update and describe climate, including possible changes in the frequency and intensity of weather and extreme events, for planning and engineering design of the built and natural environments.
- Identify (and evaluate) methods to assess impacts and vulnerabilities caused by changing climate conditions on the built and natural environments
- Promote communication of best practices for addressing uncertainties associated with changing development and conditions at the project scale, including climate, weather, extreme environments and the nature and extent of the built and natural environments, in civil engineering practice.

This paper consists of the following sections:

- "Review of Climate Science for Engineering Practice," provides an overview of the current knowledge of climate and weather science as well as its limitations and its relevance to engineering practice.
- "Incorporating Climate Science into Engineering Practice," – presents the challenges of incorporating climate change and weather science into engineering practice.
- A case study in robust decision making: Addressing Uncertainty in Upper Great Lakes Water Levels
- "Summary, Conclusions and Recommendations," presents of approaches to near-term decision-making and recommendations for research, development and implementation of improved practices.
- "References," provides sources for further information.

The CACC report, upon which this paper is based, describes the impacts of climate change on buildings and other structures, coastal management, cold regions, energy supply, transportation, urban water systems and water resources. It makes

© ASCE 2014

recommendations for actions, including codes and standards, and provides additional case studies.

2. REVIEW OF CLIMATE SCIENCE FOR ENGINEERING PRACTICE

Weather, climate and their extremes are factors in civil engineering design and practice. Weather is defined as "the state of the atmosphere with respect to wind, temperature, cloudiness, moisture, pressure, etc." (NWS 2013). Weather generally refers to short-term variations on the order of minutes to about 15 days (NSIDC, 2012). Climate, on the other hand, "is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years" (IPCC 2014).

Engineering design is primarily concerned about the extremes. The IPCC (2007a) defines an **extreme weather event** as "an event that is rare at a particular place and time of year." Extreme weather varies from region to region. An **extreme climate event** would be a pattern of extreme weather that persists for some time, such as a season. Drought or heavy rainfall over a season are examples (IPCC 2007a). Climate scientists and civil engineers may not agree on how uncommon an event should be to be called extreme. The IPCC says "an extreme weather event would "normally be as rare as or rarer than the 10th or 90th percentile of the observed probability density function." However, in civil engineering terms, "rare" is often defined in terms of the acceptable frequency of failure. Large dams may be designed for events with a mean recurrence interval of about 10,000 years. Flood risk management is concerned with events with mean recurrence intervals of 100 to 500 years. Transportation and storm water design is concerned with events that occur more frequently, coming closer to the IPCC definition (Bonnin, et al. 2011).

The IPCC recently released a Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (IPCC 2012). Table 1 presents a summary of observed and projected changes to physical impacts that could affect infrastructure at a global scale.

Table 1: Summary of observed and projected changes that may affect engineering at a global scale. (Source: Table 3.1 IPCC 2012 (http://www.ipcc-wg2.gov/SREX/).

Physical Impact	Observed Changes	Projected Changes
Temper-ature	*Very likely* decrease in number of unusually cold days and nights at the global scale. *Very likely* increase in number of unusually warm days and nights at the global scale. *Medium confidence* in increase in length or number of warm spells or heat waves in	*Virtually certain* decrease in frequency and magnitude of unusually cold days and nights at the global scale. *Virtually certain* increase in frequency and magnitude of unusually warm days and

	many (but not all) regions. *Low or medium confidence* in trends in temperature extremes in some subregions due either to lack of observations or varying signal within subregions.	nights at the global scale. *Very likely* increase in length, frequency, and/or intensity of warm spells or heat waves over most land areas.
Precipita-tion	*Likely* statistically significant increases in the number of heavy precipitation events (e.g., 95th percentile) in more regions than those with statistically significant decreases, but strong regional and subregional variations in the trends.	*Likely* increase in frequency of heavy precipitation events or increase in proportion of total rainfall from heavy falls over many areas of the globe, in particular in the high latitudes and tropical regions, and in winter in the northern mid-latitudes. [
Winds	*Low confidence* in trends due to insufficient evidence.	*Low confidence* in projections of extreme winds (with the exception of wind extremes associated with tropical cyclones).
Tropical Cyclones	*Low confidence* that any observed long-term (i.e., 40 years or more) increases in tropical cyclone activity are robust, after accounting for past changes in observing capabilities.	*Likely* decrease or no change in frequency of tropical cyclones. *Likely* increase in mean maximum wind speed, but possibly not in all basins. *Likely* increase in heavy rainfall associated with tropical cyclones.
Extra-tropical Cyclones	*Likely* poleward shift in extratropical cyclones. *Low confidence* in regional changes in intensity.	Likely impacts on regional cyclone activity but low confidence in detailed regional projections due to only partial representation of relevant processes in current models. Medium confidence in a reduction in the numbers of mid-latitude storms.
Droughts	*Medium confidence* that some regions of the world have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but opposite trends also exist.	*Medium confidence* in projected increase in duration and intensity of droughts in some regions of the world, including

© ASCE 2014

		southern Europe and the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil, and southern Africa. Overall *low confidence* elsewhere because of insufficient agreement of projections.
Floods	*Limited to medium evidence* available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scale. Furthermore, there is *low agreement* in this evidence, and thus overall low confidence at the global scale regarding even the sign of these changes. *High confidence* in trend toward earlier occurrence of spring peak river flows in snowmelt- and glacier-fed rivers.	*Low confidence* in global projections of changes in flood magnitude and frequency because of insufficient evidence. *Medium confidence* (based on physical reasoning) that projected increases in heavy precipitation would contribute to rain-generated local flooding in some catchments or regions. *Very likely* earlier spring peak flows in snowmelt- and glacier-fed rivers.
Extreme Sea Level and Coastal Impacts	*Likely increase* in extreme coastal high water worldwide related to increases in mean sea level in the late 20th century.	*Very likely* that mean sea level rise will contribute to upward trends in extreme coastal high water levels. *High confidence* that locations currently experiencing coastal erosion and inundation will continue to do so due to increasing sea level, in the absence of changes in other contributing factors.
Other Impacts (Land-slides and Cold Regions)	*Low confidence* in global trends in large landslides in some regions. *Likely* increased thawing of permafrost with likely resultant physical impacts.	*High confidence* that changes in heavy precipitation will affect landslides in some regions. *High confidence* that changes in heat waves, glacial retreat, and/or permafrost

© ASCE 2014

		degradation will affect high mountain phenomena such as slope instabilities, mass movements, and glacial lake outburst floods.

The International Panel on Climate Change (IPCC 2014) in its most recent global assessment says "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased." The National Climate Assessment (NCA) (Melillo et al. 2014), released in May of 2014, reached a similar conclusion.

Practicing engineers, as well as planners, land managers, and others face a growing demand to understand and incorporate changes in weather and climate in project design and implementation. This need to anticipate future trends drives attempts to quantifiably simulate climatic processes through numerical modeling. Climate models combine scientific knowledge from a number of disciplines, including atmospheric sciences, oceanography, cryospheric sciences, hydrology, ecosystem modeling, and others, to simulate past, present and future climates. They are the best tools that climate science has to make quantitative projections of global, continental scale climatic conditions under anthropogenic forcing. Their value at the project level scale, however, is subject of much discussion and debate.

Global Climate Models (GCMs) are more commonly used to determine climate impacts, and typically consist of four main components: atmosphere, ocean, land surface, and sea ice (Climate Change Science Program 2008). These models solve equations for thermodynamics and fluid mechanics for variables of interest. Variables that describe the atmospheric state include temperature, pressure, humidity, winds, and water and ice condensate in clouds. Variables are typically defined on a spatial grid. The spatial resolution for models of the Coupled Model Intercomparison Project Phase 5 (CMIP5) vary from 0.5° to 4° for the atmosphere component and from 0.2° to 2° for the ocean component (one degree of latitude is approximately 69 miles (111 kilometers); Taylor, et al. 2012). Processes that occur over areas too small or over time periods too short to resolve on the model grid are parameterized (represented by average or typical tendencies rather than the full underlying fluid mechanics). These processes include cloud formation and dissipation and convection, and turbulent processes near the earth's surface. Topographic features, and their effects on local and regional weather and climate are not well represented in the coarser resolution scales associated with GCMs.

Assumptions about future greenhouse gas emissions are used as input to GCMs. The emissions are converted into atmospheric concentrations of greenhouse gases using

© ASCE 2014

Integrated Assessment Models (IAM) that have extremely simplified representations of atmospheric and oceanic fluid dynamics. The GHG concentrations are then input in to the GCMs which simulate the effect of those concentrations on climate. Future greenhouse gas emissions depend on future social and economic development, population changes, and technological innovation. These factors are difficult to predict and highly uncertain.

There are many sources of uncertainty in climate projections. Pielke Sr. (2004) argues that there are limits in scientists' ability to make projections of potential future climate change due to the "imperfect representation of the full complexity of the Earth system, non-linear spatial and temporal feedbacks, and imperfect foresight of human behavior." The IPCC (2012) lists three main sources of uncertainty in the projections: the natural variability of climate; uncertainties in climate model response, or sensitivity, to anthropogenic and natural forcing; and projections of future emissions and other natural and anthropogenic climate drivers. The uncertainty in the response of the climate system to these drivers is manifest in the structure and parameter choices in climate models. Uncertainty in climate model parameters include the uncertainty in the representation of physical processes, such as cloud formation and land cover effects, that largely occur at spatial scales smaller than the large spatial scale used in climate models. Some examples of complex and non-linear feedbacks include biogeographical processes such as changes in the distribution and composition of vegetation, land use changes caused by man, and deep ocean circulation effects on ocean temperature and salinity. Barsugli, et al. (2009) state "(1) Climate model simulations have generally improved since the early 1990s in their ability to simulate the observed mean climate and seasonal cycle; (2) Despite the increase in model performance over the last two decades, the range of climate projections across all models has not appreciably narrowed; (3) The actual uncertainty of global and regional climate change (as scientists understand it) is larger than the range simulated by the current generation of models."

3. INCORPORATING CLIMATE SCIENCE INTO ENGINEERING PRACTICE

Engineers build long-lived infrastructure. The right-of-ways and footprints of the infrastructure have even longer-term influences. Thus the planning and design of new infrastructure should account for the climate of the future. Considering the impacts of climate change in engineering practice is analogous to including forecasts of long-term demands for infrastructure use as a factor in design. Though the scientific community agrees that climate is changing, there is significant uncertainty about the spatial and temporal distributions of the changes over the lifetime of infrastructure designs and plans. The requirement that engineering infrastructure meets future needs and the uncertainty of future climate is a challenge to engineers.

© ASCE 2014

Infrastructure designs and plans, as well as institutions, regulations and standards to which they must adhere, will need to be adapted and even be adaptable to accommodate a range of future climate conditions. Secondary effects from a changing climate such as changes in land cover/use, resource availability and demographics in population will be similarly uncertain and will require flexibility in infrastructure location and design. The standards, codes, regulations, zoning laws, etc., which govern infrastructure are often finely negotiated or delicately balanced legally, which often makes them slower to adapt. In addition, different stakeholders may exploit the uncertainties associated with climate change to argue for a positions they prefer. This section provides a review of engineering practices and discusses how engineers can consider climate change in their practice given the uncertainty of the future. Incorporating climate change into engineering practice will require engineering judgment to balance costs and potential consequences of failure.

Engineering practice recognizes and accounts for uncertainties in future conditions. These methods include designing for a flood or wind velocity of a particular magnitude, the use of safety factors or freeboard, and probabilistic and statistical methods. Engineers use statistical methods to quantify uncertainty for empirical probability distributions used in engineering design. The assumption of stationarity implies that the statistical properties of extremes in future time periods will be similar to those of past time periods. Recent papers have noted that climate change undermines this assumption (Milly et al. 2008).

Even without climate change, climate varies naturally on decadal and longer time scales, and the observed record is a relatively short time period compared to the potential range of climate variability. There are also multiple other sources of change and uncertainty: changes in demand for infrastructure and services, changes in land use, urbanization, population increase, and economic development in vulnerable areas such as floodplains, deserts, shorelines and earthquake zones. Population and development may stress natural resources, such as increased groundwater depletion, surface water withdrawals, and deforestation. In addition, society and engineers are increasingly concerned about the natural environment. Changes in ecosystems and species composition are particularly uncertain.

Risk analysis and management is the primary approach engineers take to deal with future uncertainty (Ayyub 2014). Risk is commonly measured in simple terms as the probability of occurrence of an event and the outcomes or consequences associated with occurrence of an event. Risk assessment is primarily concerned with three questions: (1) what can happen? (i.e., what can go wrong?); (2) how likely is it that that it will happen?; (3) if it does happen, what are the consequences? (Kaplan and Garrick 1981). Risk assessment is a systematic process to identify potential uncertain events (or hazards), determine the consequences if the event occurs, and to estimate its likelihood of occurrence.

The uncertainty associated with future climate is not completely quantifiable and, therefore, if it is to be used in engineering practice it will require engineering

© ASCE 2014

judgment. Decision methods that account for this uncertainty may be employed, such as robust decision making (Groves and Lempert 2007; Groves, et al. 2008; Lempert, et al. 2003). One approach to decision making is to choose robust alternatives that do well across a range of possible future conditions. The case study on Lake Superior regulation in Section 4 used robustness as a decision criterion in choosing regulation rules.

The mathematical objective here could be to "minimize the maximum regret," where regret is the difference between a plan payoff in a given scenario and the payoff of the best performing plan under that same scenario. In common usage, low regret strategies are policies that would work well under both the current climate and an uncertain future climate. "No regret" is a term that is commonly used; however, most alternatives usually have a cost that is borne by someone who may "regret" the policy.

Engineers will not be able to predict all the potential conditions for future infrastructure and systems. In addition to anticipating a range of possible future conditions, designs should be flexible. Flexible design includes the ability to change size and/or functions in the future. Flexible designs would also include redundant systems to protect against failures (de Neufville and Scholtes 2011).

A risk management framework should ensure that a system can be updated over time as conditions change. Such a framework would include a monitoring program to evaluate system performance over time and flexibility to make needed changes. A climate change risk management program can be incorporated into an organization's asset management program. An asset management system is a "strategic and systematic process of operating, maintaining, upgrading, and expanding physical asset effectively throughout their life cycle" (FHWA 2012). Asset management programs usually collect performance data over the life cycle of a system that can be used to evaluate the system's performance under new and changing conditions.

The Observational Method, well established in Geotechnical Engineering (Terzaghi and Peck 1948), can be used to deal with uncertainties in future extreme conditions as well as uncertainties in foundation conditions.

- Project design would be based on the most probable climate condition(s) rather than the most unfavorable. The most unfavorable conceivable deviations from the most probable conditions would be identified.

- A course of action or design modification would be devised (in advance) for every foreseeable unfavorable climate deviation from the most probable condition(s).

© ASCE 2014

- The performance of the project would be observed over time and the response of the project to observed changes assessed. The observations should be reliable, reveal the significant phenomena, and be reported to encourage prompt action.

- Design, construction and operational modifications would be implemented in response to observed changes throughout the service life.

There also is useful guidance in the concept "long life, loose fit, low energy" expressed by Gordon (1972):

- Long life contributes to sustainability and reduction of greenhouse gas emissions through conservation of materials and energy required for removal and replacement.
- Loose fit means making infrastructures adaptable to conditions that could not be foreseen during the original design - a quality already widely exemplified by older systems and components in useful service today.
- Low energy, including the embodied energy in original construction and the operating energy over the service life, provides both economic benefits and reductions in the greenhouse gas emissions driving climate change.

Civil engineers use standards-based designs for infrastructure systems, such as designing for a flood of a certain return period. Engineering standards may need to be revised to account for the uncertainty of a changing climate.

4. LAKE SUPERIOR REGULATION: ADDRESSING UNCERTAINTY IN UPPER GREAT LAKES WATER LEVELS

The International Upper Great Lakes Study recommended an improved regulation plan for outflows from Lake Superior to the International Joint Commission. The new plan - *Lake Superior Regulation Plan 2012* - is more robust than the existing plan, both for historical climate and future climate states, and provides important benefits, especially to the environment. The Study employed over 100 experts and scientists from many of the top research centers in Canada and the U.S. The recommendations of the Study Board on climate-related issues of uncertainty are among the highlights of their final, peer-reviewed report to the International Joint Commission, marking the end of the $15 million five-year study (2007-2012). The Study was conducted under traditional water resources planning guidelines that included a comprehensive consideration of all the water-using sectors (municipal and industrial water supply, irrigation, hydropower) and those affected by varying lake levels (ecosystems, navigation, riparian homeowners, recreation industry). The full report can be seen at:
http://www.iugls.org/files/tinymce/uploaded/content_pdfs/Lake_Superior_Regulation_Full_Report.pdf

© ASCE 2014

In view of the uncertainty emerging from early results of climate change research, the IUGLS Board decided to undertake a broader exploration and evaluation of how the results of that research could be used best and how decisions should be made. The result was the development of a fairly straightforward but relatively innovative process for using various sources of climate information to inform the evaluation of alternative regulation options and decision making. The focus of the approach is to first characterize the sensitivity of a decision to changes in climate conditions, and then evaluate the impacts of such changes based on a variety of climate information sources and their relative credibility as assessed by expert judgment – i.e. the independent Study Board that reported to the IJC.

Adaptation to climate change was one of the principal goals of the Study from its outset. The Study was the third comprehensive assessment in the last 40 years to address a recurring challenge in the upper Great Lakes system: *how to manage fluctuating lake levels in the face of uncertainty over future water supplies to the basin while seeking to balance the needs of those interests served by the system*. The Study Board developed several planning objectives which guided the formulation of scores of alternative options and the fundamental evaluation criteria.

The Study took the approach that there were many sources of information, each with their own associated uncertainties. Rather than simply relying on downscaling a suite of climate change projections ('top-down'), they undertook a 'decision-scaling' approach (Brown, et al. 2011) which asked a series of fundamental questions associated with existing operation of the system: under what climate circumstances would the system 'fail'?; what does 'failure' mean for each of the water-using/dependent entities?; what are the options for mitigating service delivery failure? In other words, it was a more conventional 'bottom-up' engineering perspective, reflecting a logical evaluation process of defining the conditions for system operation and failure points, and then looking through various sources of information (Stakhiv 2011). This included traditional hydrologic analyses; stochastic analysis, paleo-climatic evidence and GCM model scenarios to determine where there was a confluence of data and evidence which provided a higher degree of confidence in the final choice of 'robust' options by the Study Board.

Undertaking an analysis of future climate related impacts on the upper Great Lakes required the development of cutting edge scientific information and methods for analysis. In particular, the Study found that changes in lake levels may not be as extreme over the next 30 years as previous studies have predicted. This finding reflects a trend of increasing evaporation, likely due to lack of ice cover, and increasing water temperatures and wind speeds, with the resulting reduction in water supplies largely offset by increased precipitation. Projections suggest that lake levels will remain within a relatively narrow historical range with lower levels likely though higher levels are possible at times.

Limitations in model projections of future hydroclimate conditions resulted in significant uncertainty beyond the next 30 years. While lower lake levels were

© ASCE 2014

considered likely, the possibility of higher levels could not be dismissed. Both possibilities were considered in the development of a new regulation plan. Therefore, in terms of water management and lake regulation, the best approach is to make decisions in such a way as to not overly rely on assumptions of particular future climatic and lake level conditions or specific model projections. Robustness – the capacity to meet regulation objectives under a broad range of possible future water level conditions – was a primary objective of any new regulation plan. As a result, the Study Board considered four broad conditions that subsumed 13 scenarios that encompassed the widest range of plausible futures. Each was based on a different hypothesis about the impact of varying climate, and represented by a subset of net basin supply (NBS) data series from different models selected to test plans under each scenario. In order for the Study Board to endorse a plan, the selected plan had to perform as well as any other plan for all four of the scenarios.

The process used "robustness" as the 'tie breaking' decision criterion when comparing options that were nearly equal in their economic, environmental and social performance indicators for the 'historical' sequence of hydrology. Robustness was defined as performing well over a wide variety of projected future climate conditions.

A major goal of the Study was to bring the best possible hydroclimatic science to bear on selecting a robust regulation plan. In working towards that objective, the Study included state-of-the-science climate projections from one of the largest ensembles of GCM runs ever assembled for a regional study, regional climate modeling from two separate national modeling centers, a variety of statistical modeling approaches and innovations in modeling of the lake system's responses to climate. Climate research showed that changes in lake levels in the near-term future may not be as extreme as previous studies have predicted. For example, comparing the results of statistically down-scaled GCMs with results of dynamical down-scaled GCM projections, the Study found that predicted changes in net basin supplies (NBS) for the design period of year 2040 varied considerably, with both drier or wetter conditions predicted depending on the models used and their resolution. The Study's hydroclimate findings represent major steps forward in improving understanding of the largest regulated freshwater system in the world.

Yet despite best efforts, in terms of understanding the lakes system relative to lake levels, the unavoidable conclusion from the Study was that the Great Lakes are a complex system whose dynamics are only partially understood, and this current state of understanding has its limitations for deriving projections of the future. Furthermore, at present there is no evidence that the statistics of the historical record are not valid. The current record of Great Lakes NBS appears continuingly stationary, marked by strong interannual and decadal variability, and showing no response that may be attributable to climate change. During the planning period (i.e., 30 years), "natural variability" is likely to mask any forcing due to greenhouse gas emissions. Lake levels are likely to continue to fluctuate, but still remain within a relatively narrow historical range. While lower levels are likely, the possibility of

© ASCE 2014

higher levels cannot be dismissed but rather must be considered in the development of a new regulation plan. The best approach, therefore, is to make decisions in such a way as there is not great reliance on assumptions of the future.

The Study developed an Adaptive Management strategy for dealing with extreme water levels associated with climate uncertainties that were outside the bounds of our ability to regulate lake levels. Lake regulation, by its nature, is highly flexible and is compatible with adaptive management principles – in that operating rules can be relatively easily adjusted as climate variables change and better information becomes available. This adaptive management strategy can help interests better anticipate and respond to future extreme water levels.

Adaptive management is a planning process that provides a structured, iterative approach for improving actions through long-term monitoring, modeling and assessment. It allows decisions to be reviewed, adjusted and revised as new information and knowledge becomes available or as conditions change. These are some of the features of a long-term adaptive management strategy that the Study Board proposed for the upper Great Lakes, devised to address future extreme water levels in the Great Lakes-St. Lawrence River basin through six core initiatives:

- Strengthening hydro-climatic monitoring and modeling;
- Ongoing risk assessment;
- Ensuring more comprehensive information management and outreach;
- Improving tools and processes for decision makers to evaluate their actions;
- Establishing a collaborative regional adaptive management study for addressing water level extremes; and,
- Promoting the integration of water quality and quantity modeling and activities.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Civil engineers have responsibilities for the planning, design, construction, operation and maintenance of physical infrastructures. These infrastructures include buildings of all types, communication facilities, energy generation and distribution facilities, industrial facilities, transportation networks, water resource facilities and urban water systems. They are expected to remain functional, durable and safe for long service lives, typically 50 to more than 100 years. They are exposed to, and potentially vulnerable to, the effects and extremes of climate and weather such as droughts, floods, heat waves, high winds, storm surges, accumulated ice and snow, and wildfires. Engineering practices and standards are intended to provide acceptably low risks of failures in functionality, durability and safety over the service lives of infrastructure systems and facilities.

Climate scientists have reached near-unanimous consensus that climate has changed in the past, will continue to change in the future, and although natural

© ASCE 2014

factors still affect climate, human activities are now the dominant agents of change. The following characteristics of future climate are accepted by the vast majority of climate scientists: substantial increases in temperature; related increases in atmospheric water vapor; increases in extreme precipitation and intensity in most areas and global sea-level rise.

Global climate models (GCMs) are the primary tool that climate scientists use to make quantitative projections of future global and regional climate. Climate models project systematic changes in climate and weather conditions.

Climate projections introduce additional climatic uncertainty beyond those that can be estimated from observations of the past. For example, there is significant uncertainty regarding the magnitude and rate of climate warming over the design life of the systems and elements of our built environment. Engineering design is primarily concerned with climate and weather extremes, but the projection of future extreme events and their frequency of occurrence have even greater uncertainty. GCMs tend to underestimate the variance and serial persistence in observed climate, which implies that they may underestimate climate extremes. Engineering design and planning is generally conducted at the regional and local scales, but GCMs perform better at lower resolution spatial scales and longer time temporal scales. Downscaling techniques are used to obtain higher resolution regional and local projections. Downscaling creates local and regional information, but it does not reduce the uncertainty. In fact, the uncertainty is much larger on regional and local scales.

The long-lived nature of infrastructure and the even longer-term influence of the associated right-of-ways and footprints suggest that the planning and design of new infrastructure should account for the climate of the future. Considering the impacts of climate change in engineering practice is analogous to including forecasts of long-term demands for infrastructure use as a factor in design. However, even though the scientific community agrees that climate is changing, there is significant uncertainty about the location, timing and magnitude of the changes over the lifetime of infrastructure. The requirement that engineering infrastructure meets future needs and the uncertainty of future climate at the scale of the majority of engineering projects leads to a dilemma for practicing engineers. The dilemma is the gap between climate science and engineering practice that must be bridged.

The gap can be bridged by characterizing and quantifying (to the degree possible) uncertainty in future climate and accounting for that uncertainty in planning and design decisions. Risk analysis and management is the primary approach engineers take to deal with future uncertainty. Typically, engineering practices and standards have been based on assumed stationarity of extremes of climate and weather – that the frequencies and intensities of extremes observed in the past adequately represent those that will occur in the future. This assumption may not be valid under a changing climate. However, it is also problematic to estimate the probabilities of future climate events from climate models. The uncertainty of

© ASCE 2014

future climate is not quantifiable. Engineers can attempt to make plans and designs adaptable to a range of future conditions of climate, weather, extreme events and societal needs for infrastructure. However, there will be a tradeoff between the cost of increasing system reliability with the potential cost and consequences of future failure.

Considering the above information the following recommendations are appropriate:

- Engineers should communicate and collaborate with climate scientists to observe and model climate, weather and extreme events. The purpose of the involvement is to improve the relevance of the modeling and observations for use in the planning, design, operation, maintenance and renewal of the built and natural environment. It is only when engineers work closely with climate scientists that the needs of the engineering community will be fully understood, limitations of the climate science community will be more transparent to engineers, and the uncertainties of the projections of future climate for engineering design purposes are fully recognized.
- Practicing engineers, project stakeholders, policy and decision makers should be informed about the uncertainty of the projections of future climate and the reasons for the uncertainty as elucidated by the climate science community. Because the uncertainty associated with future climate is not completely quantifiable, if projections of future climate are to be used in engineering practice it will require considerable engineering judgment to balance the costs of mitigating risk through adaptation against the potential consequences of failure.
- Engineers should develop a new paradigm for engineering practice in a world in which climate change may occur but cannot be projected with a high degree of certainty. When it is not possible to fully define and estimate the risks and potential costs and reduce the uncertainty in the timeframe in which action should be taken, it may be feasible to use low regret, adaptive strategies such as the observational method to make a project more resilient to future climate and weather extremes.
- Critical infrastructure that is most threatened by changing climate in a given region of the country should be identified and the public and decision makers should be made aware of this assessment. An engineering-economic evaluation of the costs and benefits of strategies for resilience of the critical infrastructure should be undertaken.

REFERENCES

Ayyub, Bilal M. 2014, *Risk Analysis in Engineering and Economics*, Second edition, Chapman and Hall/CRC.

Barsugli, Joseph, Chris Anderson, Joel B. Smith, and Jason M. Vogel, (2009). *Options for Improving Climate Modeling to Assist Water Utility Planning for Climate*

© ASCE 2014

Change. Prepared for: Water Utility Climate Alliance (WUCA), Available at http://www.wucaonline.org/assets/pdf/pubs_whitepaper_120909.pdf

Bonnin, Geoffrey M., Kazungu Maitaria, and Michael Yekta, (2011). Trends in Rainfall Exceedances in the Observed Record in Selected Areas of the United States. *Journal of the American Water Resources Association* (JAWRA) 47(6): 1173–1182.

Brown C, Werick W, Leger W, Fay D., 2011. A decision analytic approach to managing climate risks: application to the Upper Great Lakes. Journal of the American Water Resources Association 2011, 47:524–534.

Climate Change Science Program (CCSP), (2008). *Climate Models: An Assessment of Strengths and Limitations*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Energy, Office of Biological and Environmental Research, Washington, D.C., USA, 124 pp.

De Neufville, Richard, and Stefan Scholtes, 2011. Flexibility in engineering design. The MIT Press, Cambridge, MA.

Federal Highways Administration (FHWA), 2012. *Transportation Asset Management Guide: A Focus on Implementation*. http://www.fhwa.dot.gov/asset/hif10023.pdf.

Gordon (1972) "Designing for Survival: the President introduces his Long Life/Loose fit/Low Energy Study," Royal Institute of British Architects Journal, vol. 79, no. 9, p. 374-376. http://www.guardian.co.uk/news/1999/jul/29/guardianobituaries3

Groves, D. G., D. Yates, and C. Tebaldi, (2008). Developing and Applying Uncertain Global Climate Change Projections for Regional Water Management Planning," *Water Resources Research*, 44, W12413, doi:10.1029/2008WR006964, 2008.

Groves, D.G. & Lempert, R.J. (2007). A New Analytic Method for Finding Policy-Relevant Scenarios. Global Environmental Change. 17 (1), 73-85.

Intergovernmental Panel on Climate Change (IPCC), (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

Intergovernmental Panel on Climate Change (2014), Fifth Assessment Report (AR5) http://www.ipcc.ch

International Upper Great Lakes Study Board (IUGLS), (2012). *Lake Superior Regulation: Addressing Uncertainty in Upper Great Lakes Water Levels.* Report to the International Joint Commission. March 2012, 215pp.

Kaplan, Stanley, and B. John Garrick, 1981. "On the Quantitative Definition of Risk," *Risk Analysis,* 1(1): 11-27.

Lempert, R. J., S.W. Popper, and S.C. Bankes, (2003). Shaping the Next One Hundred Years New Methods for Quantitative Long-Term Policy Analysis, Rand.

Melillo, J.M., Richmond, T.C., Yohe, G.W. Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program.

© ASCE 2014

Milly, P.C.D., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzwicz, Z.W., Lettenmaier, D.P., Stouffer, R.J., (2008). Stationarity is Dead: Whither Water Management? Science, Vol. 319, no 5863, pp. 573-574.

National Weather Service, National Weather Service Glossary (http://w1.weather.gov/glossary/; accessed on March 14, 2013.

National Snow and Ice Data Center (NSIDC), (2012). Arctic Climatology and Meteorology Glossary (http://nsidc.org/arcticmet/glossary/weather.html; accessed October 9, 2012).

Olsen, J. R., Ayyub, B.M, Barros, A., Beucler, B., Harding, B., Heller, M., Krakauer, N.Y., Lei, W., Lombardo, F, Lund, J.R., Medina, M., Samaras, C., Smith, J., Smith, O.P., Stakhiv, E.Z., Tan, J., Vinson, T.S., Walker, J.D., Wright, R.N., (2014), Bridging the Gap between Climate Science and Civil Engineering Practice, Committee on Adaptation to a Changing Climate, American Society of Civil Engineers.

Pielke, R.A., Sr., (2004). "Introduction," (Chapter E.1) in *Vegetation, water, humans and the climate: A new perspective on an interactive system.* Springer, Berlin, *Global Change - The IGBP Series*, pp. 485-490.

Stakhiv, Eugene Z., 2011. Pragmatic Approaches for Water Management Under Climate Change Uncertainty. Journal of the American Water Resources Association (JAWRA) 47(6):1183–1196. DOI: 10.1111/j.1752 1688.2011.00589

Terzaghi, Karl and Peck, Ralph B., *Soil Mechanics in Engineering Practice,* John Wiley and Sons, NY. 1948, pp 219, 308 & 494.

© ASCE 2014

NYC Wastewater Resiliency Plan: Climate Risk Assessment and Adaptation

Pinar Balci[1], Ph.D. and Alan Cohn[2]

[1,2]New York City Department of Environmental Protection, Bureau of Environmental Planning and Analysis, 5917 Junction Blvd., Flushing, NY; email: pbalci@dep.nyc.gov; acohn@dep.nyc.gov

ABSTRACT

The New York City Department of Environmental Protection (DEP) owns and operates one of the largest wastewater collection and treatment systems in the world, with many waterfront facilities that are vulnerable to flooding, as was evident during Hurricane Sandy when a number of facilities suffered extensive damage. This vulnerability is likely to increase over time, as climate change projections anticipate more extreme storm surge events and continued sea level rise in the next several decades. As such, DEP has taken a proactive stance in assessing its infrastructure vulnerabilities and setting forth a framework to implement protective measures. In October 2013, DEP released the NYC Wastewater Resiliency Plan (NYC DEP, 2013), the nation's most detailed and comprehensive assessment of the risk climate change poses to a wastewater collection and treatment system. Building upon previous studies, the DEP's 2013 citywide risk assessment and adaptation study sets forth a cost-effective strategy for reducing flooding damage to wastewater infrastructure and safeguarding public health and the environment. This comprehensive study examined buildings and infrastructure at DEP's 96 pumping stations and 14 wastewater treatment plants, identifying and prioritizing infrastructure that is most at-risk of flood damage. DEP developed a set of cost-effective protective measures that are tailored to each facility to improve resiliency in the face of future flood events. The study revealed a number of key results: All 14 wastewater treatment plants and 60% of pumping stations (58 out of 96) are at risk of flood damage. The study estimates that equipment valued at more than one billion dollars is at risk and requires additional protection. The recommended protective measures, totaling $315 million in improvements, are costly but critical. Increased resiliency not only reduces damage costs during a flood event, but also enables rapid recovery of full service following a flood event, prevents sewage backup into homes, and reduces the likelihood of release of untreated sewage into the environment. DEP will work to implement the recommended actions to increase resiliency through new design standards and capital projects, and is currently seeking funding through the EPA Storm Mitigation Loan Program.

© ASCE 2014

INTRODUCTION

The New York City Department of Environmental Protection (DEP) owns and operates 7,500 miles of sewers, 96 pumping stations, and 14 wastewater treatment plants that employ advanced biological and chemical processes to treat more than 1.3 billion gallons of wastewater every day.

As one of the United States' largest water and wastewater utilities, DEP is grappling with considerable infrastructure needs at a time of fiscal constraints and increasing federal and state regulatory mandates. Many DEP facilities are more than 30 years old; some of the assets have been in service for more than a century. Failure of a critical piece of equipment or system has a direct impact on public health and safety and quality of life of the 9 million New Yorkers and visitors we serve each day. While DEP has been studying the impacts of climate change on its infrastructure since the early 2000s, Hurricane Sandy and other recent climate-related events have necessitated a harder look at the requirement for climate resiliency in its infrastructure planning process.

Hurricane Sandy Impacts

Hurricane Sandy caused water levels to rise along the entire East Coast from Florida to Maine. The highest storm surges and greatest inundation on land occurred in the states of New Jersey, New York, and Connecticut, especially in and around the New York City metropolitan area. In many of these locations, especially along the coast of central and northern New Jersey, Staten Island, and southward-facing shores of Long Island, the surge was accompanied by powerful damaging waves (Blake et al., 2012). The storm's track was unprecedented, taking a sharp westward turn into the New Jersey coast rather than veering eastward out to sea. The storm also hit at high tide, which exacerbated flooding. At its peak of more than 14 ft at the Battery, the surge was three feet higher than the previous record. During Hurricane Sandy, 10 of the 14 wastewater treatment plants (WWTPs) DEP operates throughout the city experienced some degree of damage. The Rockaway WWTP, which treats only one percent of the city's wastewater, was the most severely affected. The interconnected, below-grade galleries that house the Rockaway WWTP process pumps and motors were completely inundated. Most of the damage to the wastewater facilities was to electrical systems: substations, motors, control panels, junction boxes, and instrumentation. In addition, due to Consolidated Edison and Long Island Power Authority power outages, many DEP facilities had to operate on their emergency generators for up to two weeks. Despite this fact, only three facilities were non-

© ASCE 2014

operational during the storm (outages ranged from several hours at the Coney Island WWTP to up to two weeks at the Rockaway WWTP). Forty-two of DEP's 96 pumping stations that help deliver wastewater to the plants were also damaged. Of those 42, the Manhattan Pumping Station at 13th Street and Avenue D was the most significantly affected. Approximately half of the pumping stations failed due to damage from floodwaters; half were non-operational because of power supply losses.

DEP rapidly deployed in-house and contract labor to restore operations at WWTPs and pumping stations. During the height of the storm, 10 of the 14 WWTPs operated at full capacity and treated two times dry weather flow using backup power generation. Given the severity of the storm, recovery was fairly quick due to the remarkable dedication of City employees. By November 1, 2012, two days after the storm, 99 percent of all New York City wastewater was being treated and by November 12, 2012, DEP had restored full secondary treatment at all 14 WWTPs, and 13 of the 14 WWTPs were processing 100 percent of wastewater entering the facilities (Figure 1). When completed, DEP estimates that the immediate damages from Sandy will top $100 million.

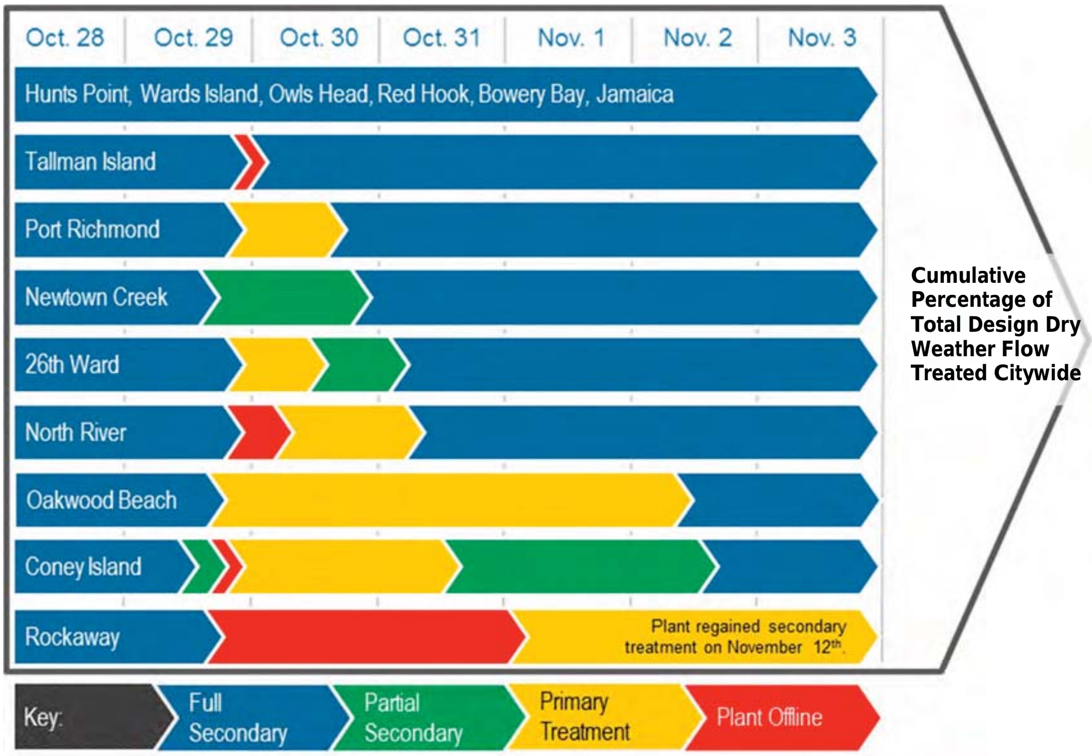


Figure 1. DEP Wastewater Treatment Plant Timeline during Hurricane Sandy

© ASCE 2014

This event, combined with projected increases in the frequency of extreme future flood events due to climate change, further enforced the need to develop a plan to harden the City's wastewater infrastructure to reduce the likelihood of damage, service disruptions, and environmental impacts from future surge events. Since it is difficult to predict when these events will happen and to what degree, DEP developed a detailed risk assessment framework, including evaluations of vulnerabilities, likelihoods of failure, impacts of failure, and appropriate mitigation strategies. The protective measures were recommended based on a triple bottom line approach, accounting for feasibility, cost of implementation, value and criticality of equipment being protected, the population and critical facilities in the service areas, and potential impacts on beaches. The findings of this risk assessment were published in the *NYC Wastewater Resiliency Plan*, which provides valuable insight to guide capital planning and operations modifications which ultimately increase the resiliency of the system.

OBJECTIVE

The objective of this presentation is to walk-through the key components of the risk assessment framework developed for the *NYC Wastewater Resiliency Plan*, including the climate, vulnerability, and adaptation assessments. The presentation will provide sample case studies on how a triple bottom line analysis was conducted to help prioritize capital projects; walk-through key assumptions and equations used to develop asset estimates, damage costs, implementation estimates, and cost-benefit ratios; discuss lessons learned; and illustrate how other agencies can use this adaptable risk management framework to perform their own assessments, building stronger, more resilient communities against future climate risks.

METHODOLOGY

The *NYC Wastewater Resiliency Plan* used a unique framework to assess flood risk and identify appropriate protective measures. This framework can be applied as a prototype to protect a wide range of vital City infrastructure beyond wastewater facilities. As shown in **Figure 2**, the framework is comprised of three major modules encompassing *climate, risk,* and *adaptation analyses:*

1) **CLIMATE ANALYSIS:**
   What is NYC's climate likely to be in the future, especially in terms of storm surge and sea level rise? What conditions should NYC prepare for?

© ASCE 2014

While climate science cannot predict when a surge will occur, current climate studies project that large surge events are likely to become more frequent in the future and will be exacerbated by sea level rise. The FEMA 100-year flood event was selected as the maximum surge assessed in this study. An additional 30 inches of flooding were also added to account for future sea level rise by the 2050s, the high end of the projection from the New York City Panel on Climate Change (NYCPCC, 2009; NYCPCC, 2013).

2) **RISK ANALYSIS:**
Which infrastructure will be affected in flood events?
Potential risks at each facility were identified through site visits, analysis of facility blueprints, and interviews with facility personnel. Information about conditions during Hurricane Sandy also helped pinpoint specific risks and operational challenges. The elevations of flood pathways and infrastructure were then compared to the flood elevation defined in the **Climate Analysis** to determine which infrastructure is potentially at risk. Cost estimates for the replacement of at-risk equipment under emergency conditions, cleaning of facilities, and temporary power and pumping were developed, and then used a metric to inform the prioritization of risks. Triple bottom line impacts to the community and environment such as the number of impacted people and beaches were also evaluated.

3) **ADAPTATION ANALYSIS:**
What can be done to protect at-risk infrastructure from surges and how much will this cost?
DEP performed an extensive literature review of strategies being considered around the globe to protect against climate change and narrowed the list down to six measures that would work best for NYC's wastewater infrastructure including elevating or flood-proofing equipment, installing static barriers, sealing buildings, sandbagging and installing backup power capabilities. These protective measures were then evaluated for use at each wastewater facility. Strategy recommendations were based on a triple bottom line analysis encompassing social and environmental impacts, as well as feasibility, effectiveness, and cost.

© ASCE 2014

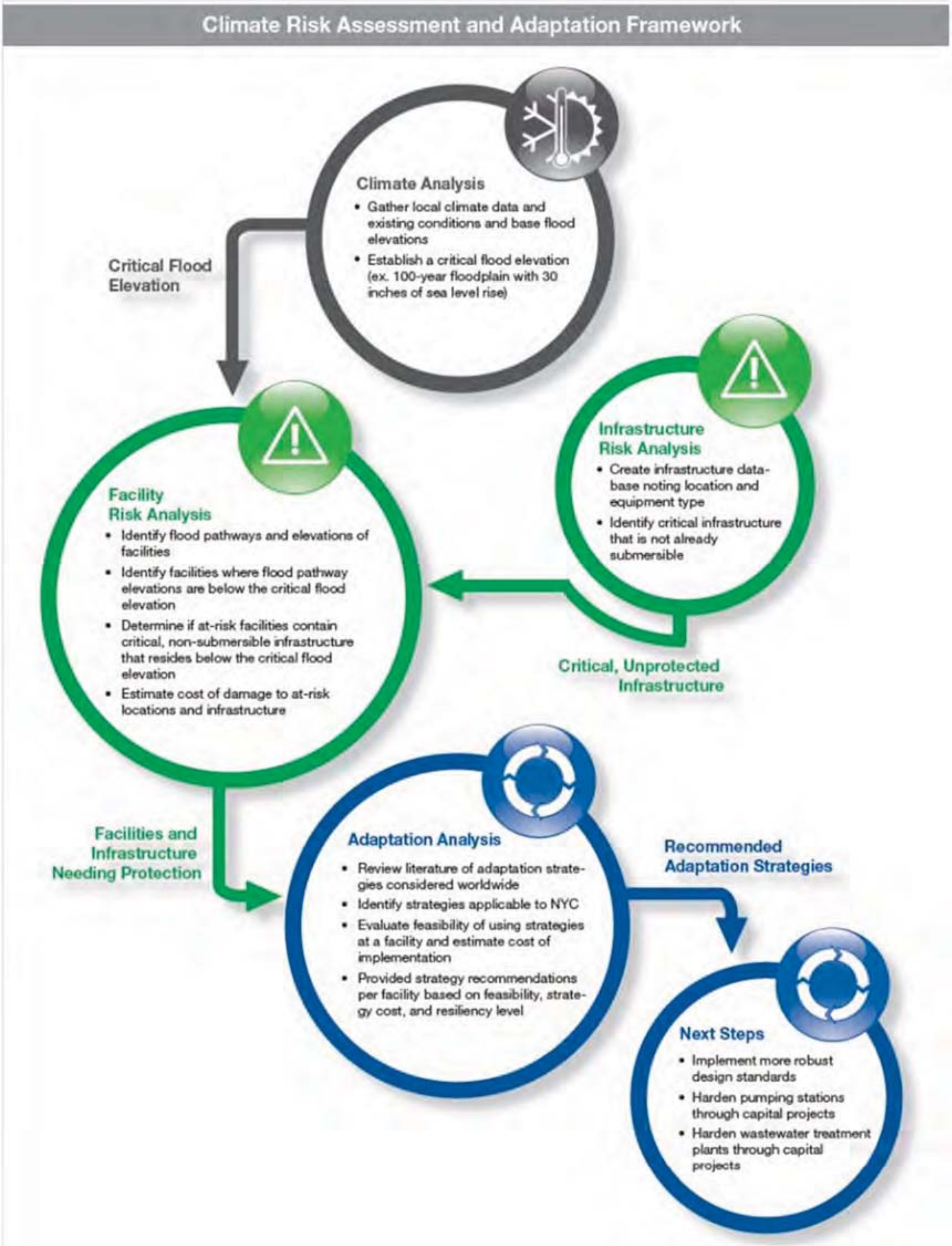


Figure 2. Climate Risk Assessment and Adaptation Framework

© ASCE 2014

FINDINGS & SIGNIFICANCE OF STUDY

This study produced a number of valuable results which demonstrate the value of risk assessment and management. The study identified flood risks at all 14 wastewater treatment plants and 60 percent of pumping stations (58 out of 96) (Figure 3) and identified critical equipment valued at more than $1 billion that is at risk and requires additional protection. It is unlikely that this high damage cost would be incurred during a single-storm surge event, as flood heights tend to vary across New York City depending on storm characteristics; however some at-risk equipment may incur repetitive damage from multiple storms over time. The risk assessment also demonstrated the monetary value of proactive adaptation. Considering the entire range of storms up to and including the 100-year flood with 30 inches of sea level rise, the cumulative damages over the next 50 years may exceed $2 billion if no protective measures are put in place. This information not only highlights areas in need of hardening, but also serves as a useful tool for operators in effectively preparing and securing various sections of facilities prior to future surge events.

The study identified a portfolio of possible adaptation strategies including six primary options which were narrowed down from a comprehensive literature review of climate resiliency measures implemented and considered in various locations around the world. These six primary strategies have a range of effectiveness and cost associated with them which include elevating equipment above critical flood elevation, making pumps submersible and encasing electrical equipment in watertight casings, constructing a static barrier around a location, sealing structures with watertight windows and doors, sandbagging temporarily, and where feasible, providing back-up power generation. Although these strategies may not necessarily

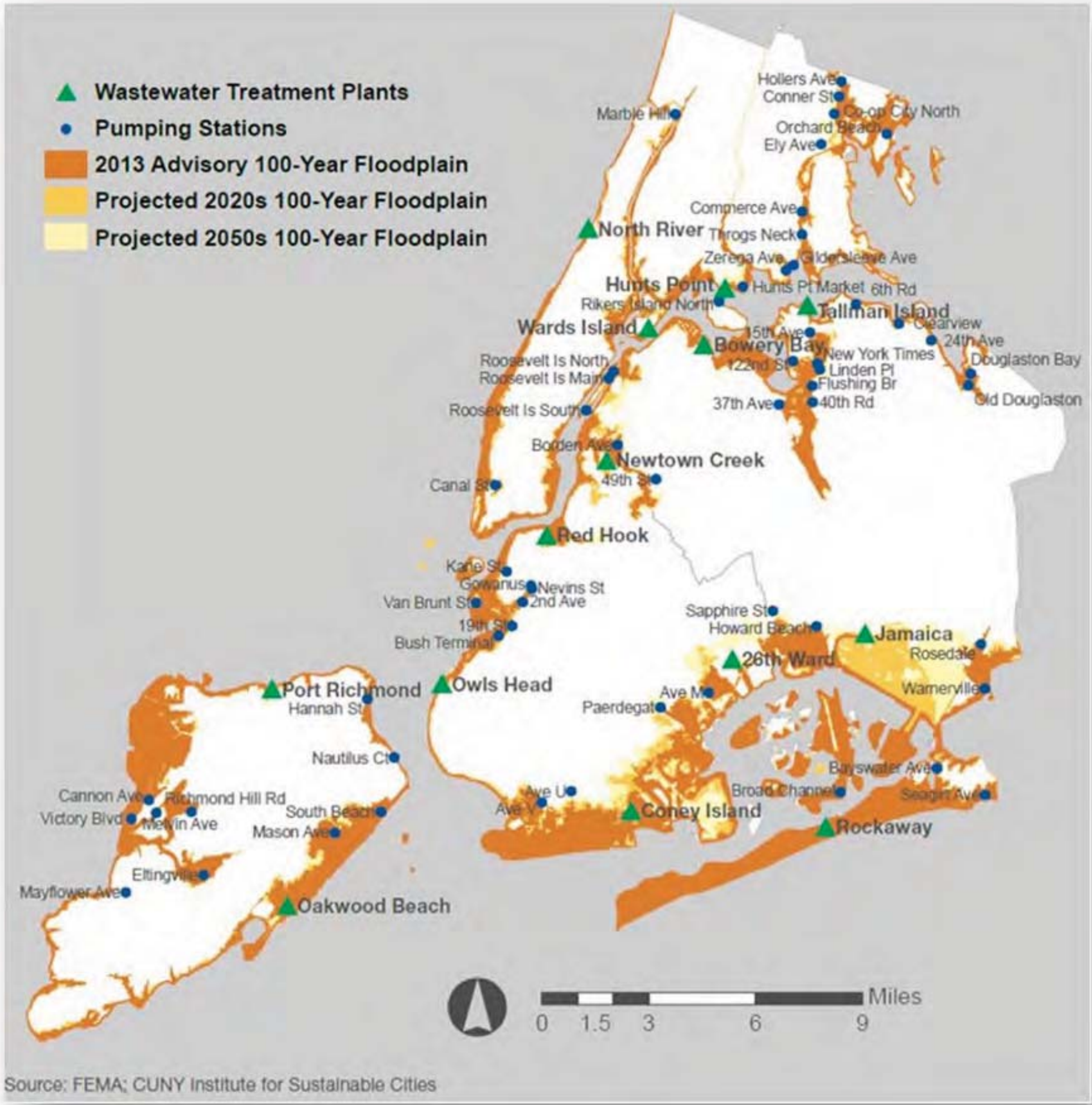
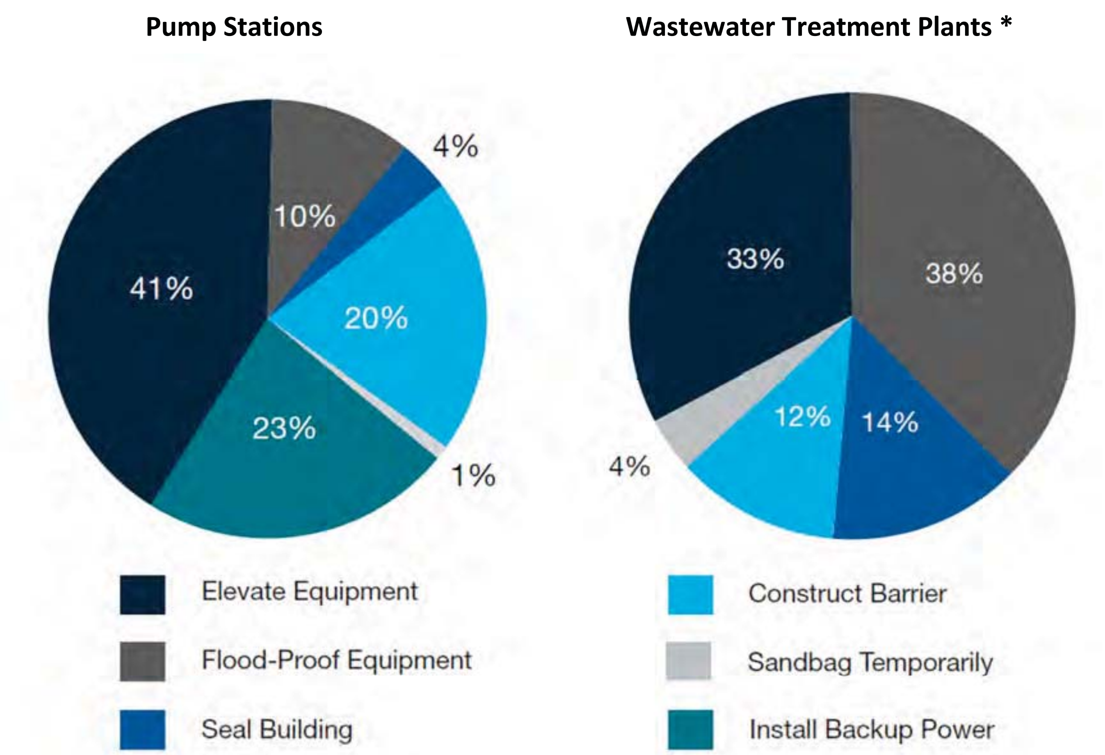


Figure 3. Wastewater Treatment Plants and Pump Stations at- Risk of Storm Surge Inundation

keep the facility fully operational during a large storm vent, the primary goal is to protect equipment from flood damage and reduce the time needed to return to normal operations following a flood event. It should be also noted that while the six strategies were analyzed in the study and recommendation were made for each wastewater facility through a design standard, planners and designers will have the option to choose which strategy is implemented at a facility based on funding

© ASCE 2014

availability and more detailed site-specific analyses. The recommended strategies for at-risk pumping stations and wastewater treatment plants are depicted in Figure 4.



*All facilities are already equipped with backup generator

Figure 4. Adaptation Strategies

The cost of the recommended adaptation measures, totaling $315 million in improvements are costly but critical in reducing damage to NYC's wastewater system from flood risk by 85% and minimize prolonged service disruptions from future storms. As previously noted, the damage costs avoided over 50 years from flood events, up to and including projected 100 year storms with 30 inches of sea level rise, may exceed over $2 billion (Figure 5). These estimates provide strong support for implementing protective measures as they will likely save the City more money as compared to the cost of repairs and disaster relief over time.

© ASCE 2014

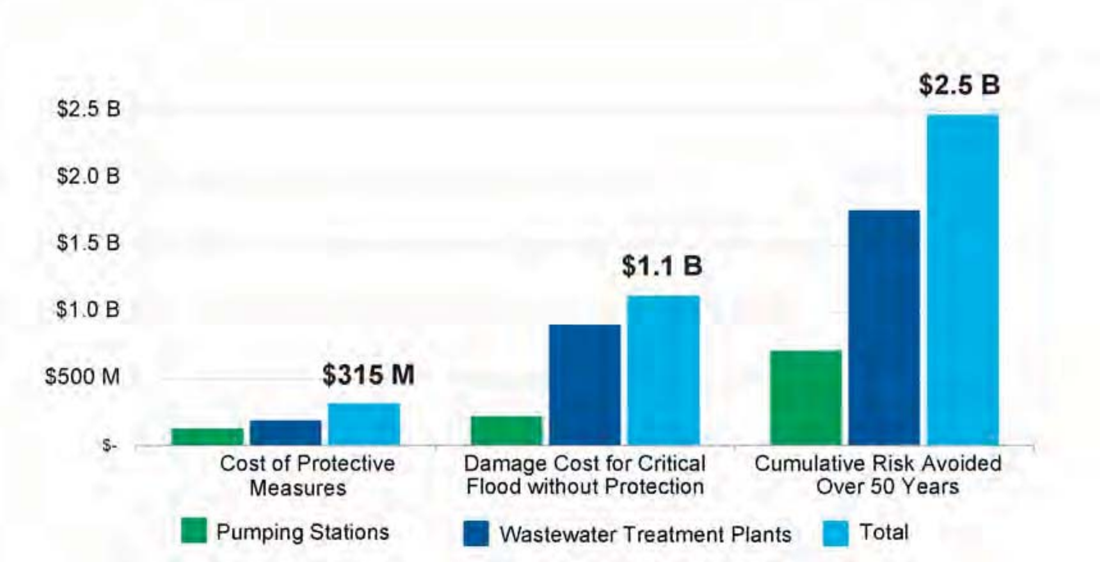


Figure 5. Summary of Estimated Costs for Wastewater Infrastructure

CONCLUSION

The study's findings detailing facility vulnerabilities and cost-effective protective strategies have been widely received by DEP operators and designers. Already, many of the suggested strategies are being considered in ongoing and planned upgrades, and the detailed cost-benefit risk analysis is providing needed justification for capital resiliency improvements, facilitating grant funding applications, and helping DEP prioritize resiliency projects.

While the magnitude of climatic change is uncertain, it is clear that the climate is warming and can bring more severe surge and sea level rise. DEP is proactively planning for climate change from reducing greenhouse gas emissions to preparing for the impacts of extreme weather to its drinking water and wastewater infrastructure. Investing in our wastewater infrastructure today will ensure the continuity of critical services well into the future. With information from this study, DEP has gained a clearer understanding of the situation to come and insight into the logistics of strategically protecting wastewater infrastructure. By implementing these strategies along with initiatives to improve energy liability, build green infrastructure, improve and expand drainage infrastructure, and promote redundancy and flexibility of our water supply, DEP will continue to be a leader in proactive planning for climate

© ASCE 2014

changes, to ensure resiliency of New York City's water resources. In addition, the framework developed in this study can serve as prototype for other coastal cities to perform their own risk assessments, building stronger and more resilient communities against future climate risks.

REFERENCES

Blake, E. S., Kimberlain, T. B., Berg, R. J., Cangialosi, J. P., and Beven, J. L. (2012). NOAA Tropical Cyclone Report, Hurricane Sandy.

New York City Department of Environmental Protection. (2013). *NYC Wastewater Resiliency Plan: Climate Risk Assessment and Adaptation Study*

New York City Panel on Climate Change, (2009). Climate Risk Information Available at: http://www.nyc.gov/html/om/pdf/2009/NPCC_CRI.pdf

New York City Panel on Climate Change, (2013). Climate Risk Information Available at: http://www.nyc.gov/html/planyc2030/downloads/pdf/npcc_climate_risk_information_2013_report.pdf

© ASCE 2014

Rationale for studying how Institutional Capacity can Influence the Adoption of Decentralized Approaches to Stormwater Infrastructure

Nicole BARCLAY[1] and Leidy KLOTZ[2]

[1] Graduate Research Assistant, Glenn Department of Civil Engineering, Clemson University, Lowry Hall, Clemson SC 29634; email: nmbarcl@g.clemson.edu

[2] Associate Professor, Glenn Department of Civil Engineering, Clemson University, Lowry Hall, Clemson SC 29634; email: leidyk@clemson.edu

ABSTRACT

In this paper we describe our rationale and preliminary plan for studying the impact of institutional capacity on the development of decentralized stormwater infrastructure. As a critical link in the water cycle, stormwater management is vital to the health of human beings and ecosystems, especially with continued rapid urbanization. In many cases, decentralized stormwater management (e.g. bioretention areas, green roofs, and permeable pavements) is technically and economically preferable to more centralized networks of pipes, channels, and treatment plants. Yet, even when they appear better, decentralized approaches are not always used. Institutional capacity, the ability to perform required tasks, of the various infrastructure institutions may help explain this missed opportunity. Drawing on the literature, we will study institutional frameworks within which stormwater management projects are developed. Questions guiding our proposed research include: To what extent are existing institutional barriers inhibiting decentralized stormwater management? How do these differ (e.g. between developed and developing countries and between corporations and communities)? Our hope is that a better understanding of the relationship between institutional capacity and decentralized approaches will improve stormwater management decisions. For example, we see potential to learn from other cultures to identify ways to encourage acceptance of decentralized stormwater in the U.S.

STORMWATER MANAGEMENT AND HUMAN HEALTH

It is expected that approximately 60% of the world's population will be living in urban areas by 2030 (United Nations, 2013) and most of this will be in developing countries. As a direct result, there is a rapidly increasing demand for infrastructure restoration and new infrastructure development (Sahely et. al, 2005). However, infrastructure needs oftentimes cannot keep up with fast growing population rates (Varis & Somlyódy, 1997). Issues such as climate change add to the challenge since with that comes uncertainty and increased intensity of natural disasters (Van Aalst, 2006) such as hurricanes, and increased intensity and frequency of rainfall. One of the critical needs to support population densities in urban areas is urban stormwater drainage (Bartone, 1991). Because it is connected to components of the water cycle including water use, water supply and natural water

© ASCE 2014

resources (Butler & Parkinson, 1997), stormwater management is vital for human health and well-being.

Rapid worldwide urbanization has caused an unprecedented increase in impervious cover due to the accepted development practices that encourage more roads, parking lots, driveways and buildings (Grimm et al., 2008). This increase in impervious cover dramatically reduces soils' infiltration capacities, increases surface runoff, and alters urban hydrology. The combination of these issues cause increased flooding, degraded ecosystems, and diminished water quality (Paul & Meyer, 2001). Most susceptible to these effects are the urban areas in developing countries, where problems are exacerbated by unplanned development and delayed or lack of drainage construction (Butler & Parkinson, 1997);(Parkinson & Mark, 2005). Take for example Dhaka, an overpopulated mega-city in Bangladesh that experiences excessive rainfall during monsoon season. Decades ago, the city had 24 natural canals and large natural wetlands areas which kept flood damage to a minimum (Varis, et al. 2007);(Azharul Haq, 2007). However, those natural systems were inhabited by millions of urban dwellers and altered by developers. The city now suffers flood damage and pollution due to inadequately built stormwater management systems (Azharul Haq, 2007).

DECENTRALIZED APPROACHES TO STORMWATER MANAGEMENT

Best practices for stormwater management are shifting from centralized highly engineered systems to also include decentralized systems which rely on a combination of engineering and natural processes (Novotny, 2009). In the 20th century, the sole purpose of most stormwater systems was to transport water off site as quickly as possible. These traditional stormwater management systems were typically centralized networks of pipes and channels carrying water to treatment plants (EPA, 2010). These systems function well when they are designed to accommodate development and population in a city. In many cases, it is cost effective to install the systems as the city is developing. For example, it is easier to install a storm sewer as part of a larger street construction project. However, when these systems are not installed as part of the initial city design, or when they are overwhelmed by unexpected development, they can be costly to update.

Decentralized approaches to stormwater management can complement centralized approaches by reducing stormwater runoff and discharges of polluted water offsite. These approaches generally employ technologies patterned after the natural hydrological cycle and preserve ecological structures (Roy et al., 2008). Decentralized systems employ integrative practices of techniques such as bioretention areas, green roofs, and permeable pavements (Dietz, 2007). These decentralized approaches, known as low impact development and green infrastructure, have gained recognition as sustainable stormwater management strategies. Good designs for centralized and decentralized infrastructure can be technically equivalent in terms of avoiding negative impacts from stormwater. Decentralized approaches are more likely to add social and ecological value through direct experience of natural ecosystems, physical recreation, environmental education, and opportunities for social interaction (Ahern, 2007). For example, the Baldwin Park Community in

© ASCE 2014

Orlando, Florida has an underground stormwater system that is integrated with restored wetlands. It has aesthetic and recreational benefits in addition to enhanced water quality benefits (WERF, 2009).

It is expected that there will be increasing use of decentralized stormwater management in developed countries as the technology continues to progress (Heaney & Sansalone, 2012). Decentralized approaches also offer advantages unique to developing cities, where there is little or no stormwater infrastructure, where development has overwhelmed existing infrastructure, and/or where the capital costs for centralized systems are prohibitive. Though decentralized stormwater management techniques are gaining acceptance, several barriers inhibit more widespread adoption. Decentralized approaches can be more difficult to "engineer," requiring an understanding of natural processes and unique consideration of each site. Depending on existing ecological structures, a single parcel of land may employ a number of decentralized approaches different from a neighboring parcel. Other barriers to more widespread adoption include fragments across different governing bodies and stakeholder groups, lack of institutional capacity, and general resistance to change (Roy et al., 2008).

INSTITUTIONAL CAPACITY AND STORMWATER MANAGEMENT

For any infrastructure development project, people are the most valuable asset. It is therefore important to understand institutional frameworks in which they operate and communicate their ideas. Infrastructure development involves a diverse array of stakeholders. For instance, internal direct stakeholders (e.g., owners, users), internal indirect stakeholders (e.g., investors), external direct stakeholders (e.g., planners), and external indirect stakeholders (e.g., regulatory agencies) all are prominently involved in infrastructure development decisions. These stakeholders operate in a unique culture that influences their decisions (Star, 1999);(Davis, 2006); (Vinck, 2003). For example, study of the construction industry from an economic sociology perspective found tacit social short cuts developed over time to aid coordination among particular groups. But these short cuts also could lead to reluctance to depart from industry standards and unusually high reliance on reputation (Beamish & Biggart, 2010). For reasons like this, even where technical engineering details work, perceived deviation from social norms can make seemingly better designs unpopular (Rozgus, 2009);(Hoffman & Henn, 2008);(Laustsen, 2008).

The need for understanding institutional processes affecting infrastructure planning and management were recognized for over two decades (Grigg, 1988). Though there is progress in this area, it is especially underdeveloped for urban water management (Van De Meene & Brown, 2009). Moreover, technical aspects are researched much more widely than social and institutional factors, but there needs to be a balanced understanding of all of these for sustainable advancements in stormwater management. For this research we define the components of an institution as 'rules, norms, and cultural beliefs' (Scott, 2001). These components influence communication and interactions among members of the institution. The regulatory process and the conformity to that process set the rigidity of the system. The norms describe social behavior within defined roles and explain how things are done and

© ASCE 2014

what is valued or desired (Scott, 2001). By considering the institution as a key component, we have the opportunity to examine the organizational culture of the various institutions involved in stormwater management. Elements of organizational culture influence how decisions are made and carried out (Nolan, 2002). Styles will differ among stakeholder groups. For example, decisions may be made by individuals, by group consensus, or by voting. Generally, people are make decisions based on what impacts them, which is one reason why stakeholder input is essential to developing successful projects.

Brown & Farrelly (2009) identified and categorized institutional barriers including 'uncoordinated institutional framework, insufficient resources, poor organizational commitment and limited community engagement, empowerment and participation.' Addressing the institutional barriers of stormwater projects can therefore lead to time and cost savings with increased project quality. It is important to recognize institutional responses to changes in technological developments so that capacity, the ability of the institution to fulfill its tasks, could be addressed. For this research, we propose looking at institutional capacity in relation to decentralized stormwater infrastructure implementation and management.

Guiding research questions

1. To what extent are existing institutional barriers inhibiting decentralized stormwater management?
2. How do these differ (e.g. between developed and developing countries and between corporations and communities)?

PROPOSED RESEARCH APPROACH

A more extensive literature review will be conducted on decentralization in stormwater management techniques, institutional capacity and decision making. A mixed study design involving qualitative and quantitative data through a descriptive case study and correlational design respectively will be done. A descriptive case study, described below, will be conducted. Within this case study there will be interviews (both formal and informal) with various stakeholders in involved agencies. Through the case study, barriers and further issues are expected to be uncovered. The findings will be compared against those in the literature.

The proposed case study will examine the execution of the flood mitigation and drainage improvement plan for the city Port of Spain in Trinidad and Tobago, a middle income developing nation. This drainage plan includes extensive conventional stormwater management and some low impact development strategies. The Inter-American Development Bank approved a loan for the project, including significant funding for institutional development for the executing agency and the managing agencies. The correlation design aspect will attempt to quantitatively understand the relationships between variables of institutional barriers and those of project development and management decisions. Further study will explore the degree of relationship between multiple variables to provide predictors among the variables.

© ASCE 2014

EXPECTED CONTRIBUTIONS

This research will contribute to better understanding of decision making in decentralized infrastructure systems and, ultimately, to better decisions. Institutional capacity plays a role in infrastructure development and there is no reason to believe that this will be any different for stormwater management projects. In fact, we believe the choice between decentralized and centralized stormwater infrastructure may offer some unique findings when viewed through an institutional capacity lens. For example, studying cultures where decentralized stormwater infrastructure is the norm may help us better understand how to overcome resistance to decentralized approaches in settings where it is unfamiliar. In many cases, this could involve cities in developed nations learning from cities in developing ones.

While we expect institutional capacity to influence stormwater management decisions, we also recognize that we should consider the reverse, that new types of sustainable infrastructure may precede a change in cultural values (Moore & Engstrom, 2005) which can create a shift in the institution. Again, the decentralized versus centralized choice has unique potential for compelling findings. Because they add social and cultural value by connecting people to natural systems and each other, decentralized approaches seem especially likely to induce cultural shifts (Moore & Engstrom, 2005) within institutions.

LIMITATIONS

Because our research is based on a case study, some findings will not be directly transferrable to other situations. Field research is somewhat difficult to replicate and compare and may lack generalizability (Singleton, Jr. & Straits, 2010). Despite these challenges, we believe this research is worth pursuing. Findings and approaches used can be incorporated into curricula for engineering and social and policy science students, demonstrating the value of greater integration of these disciplines. These activities target a major need in engineering education, helping U.S. educated engineers broaden their perspectives and develop creativity and innovation skills required to address rapidly evolving societal challenges like water and climate change (Duderstadt, 2005). If those who plan, design, and build infrastructure recognize the impact of the institution in which they operate and interact, on decisions, they will be better suited to manage their own decisions.

REFERENCES

Ahern, J. (2007). Green infrastructure for cities: The spatial dimension. In *Cities of the Future. Towards integrated sustainable water and landscape management* (pp. 267–283). IWA Publishing.

Azharul Haq, K. (2007). Water Management in Dhaka. *International Journal of Water Resources Development*, *22*(2), 291–311.

Bartone, C. (1991). Environmental Challenge on Third World Cities. *Journal of the American Planning Association*, *57*(4), 411–415.

Beamish, T. D., & Biggart, N. (2010). *Social Heuristics: Decision Making and Innovation in a Networked Production Market* (SSRN Scholarly Paper No. ID

© ASCE 2014

1533429). Rochester, NY: Social Science Research Network. Retrieved from http://papers.ssrn.com/abstract=1533429

Brown, R. R., & Farrelly, M. A. (2009). Delivering sustainable urban water management: a review of the hurdles we face. *Water Science & Technology*, *59*(5), 839–846. doi:10.2166/wst.2009.028

Butler, D., & Parkinson, J. (1997). Towards sustainable urban drainage. *Water Science and Technology*, *35*(9), 53–63.

Davis, H. (2006). *The Culture of Building*. Oxford University Press.

Dietz, M. E. (2007). Low Impact Development Practices: A Review of Current Research and Recommendations for Future Directions. *Water, Air, and Soil Pollution*, *186*(1-4), 351–363. doi:10.1007/s11270-007-9484-z

Duderstadt, J. J. (2005). Engineering Research and America's Future-Meeting the Challenges of a Global Economy. National Academy of Engineering.

EPA. (2010, August). Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure. Retrieved from http://www.epa.gov/owow/NPS/lid/gi_case_studies_2010.pdf

Grigg, N. S. (1988). *Infrastructure Engineering and Management*. John Wiley & Sons, Inc.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global Change and the Ecology of Cities. *Science*, *319*(5864), 756–760. doi:10.1126/science.1150195

Heaney, J. P., & Sansalone, J. J. (2012). A Vision for Urban Stormwater Management in 2050. In *Toward a Sustainable Water Future* (pp. 157–165). American Society of Civil Engineers. Retrieved from http://ascelibrary.org.libproxy.clemson.edu/doi/pdf/10.1061/9780784412077.ch17

Hoffman, A. J., & Henn, R. (2008). Overcoming the social and psycological barriers to green building. *Organization and Environment*, *21*(4), 390–419.

Laustsen, J. (2008). Energy efficiency requirements in building codes, energy efficiency policies for new buildings. International Energy Agency.

Moore, S. A., & Engstrom, N. (2005). The social construction of "green building" codes. In *Sustainable Architectures: Cultures and Natures in Europe and North America* (pp. 51–70). Taylor and Francis.

Nolan, R. W. (2002). *Development Anthropology. Encounters in the real world.* Westview Press.

Novotny, V. (2009). Sustainable urban water management. In *Water and Urban Development Paradigms: Towards an Integration of Engineering* (pp. 19–31). CRC Press/Balkema.

Parkinson, J., & Mark, O. (2005). *Urban Stormwater Management in Developing Countries*. IWA Publishing.

Paul, M. J., & Meyer, J. L. (2001). Streams in the Urban Landscape. *Annual Review of Ecology and Systematics*, *32*(1), 333–365. doi:10.1146/annurev.ecolsys.32.081501.114040

Roy, A. H., Wenger, S. J., Fletcher, T. D., Walsh, C. J., Ladson, A. R., Shuster, W. D., … Brown, R. R. (2008). Impediments and Solutions to Sustainable, Watershed-Scale Urban Stormwater Management: Lessons from Australia

© ASCE 2014

and the United States. *Environmental Management*, *42*(2), 344–359. doi:10.1007/s00267-008-9119-1

Rozgus, A. (2009). Using gray water efficiently. *Consulting-Specifying Engineer*, *45*(3), 19–20.

Sahely, H. R., Kennedy, C. A., & Adams, B. J. (2005). Developing sustainability criteria for urban infrasturcture systems. *Canadian Journal of Civil Engineering*, *32*, 72–85.

Scott, W. R. (2001). *Institutions and Organizations* (2nd ed.). Sage Publications, Inc.

Singleton, Jr., R. A., & Straits, B. C. (2010). *Approaches to Social Research* (5th ed.). Oxford University Press.

Star, S. L. (1999). The ethnography of infrastructure. *American Behavioral Scientist*, *43*(3), 377–391.

United Nations. (2013). World Urbanization Prospects, the 2011 Revision. United Nations. Retrieved from http://esa.un.org/unpd/wup/CD-ROM/Urban-Rural-Population.htm

Van Aalst, M. K. (2006). The impacts of climate change on the risk of natural disasters. *Disasters*, *30*(1), 5–18. doi:10.1111/j.1467-9523.2006.00303.x

Van De Meene, S. J., & Brown, R. R. (2009). Delving into the "Institutional Black Box": Revealing the Attributes of Sustainable Urban Water Management Regimes1. *JAWRA Journal of the American Water Resources Association*, *45*(6), 1448–1464. doi:10.1111/j.1752-1688.2009.00377.x

Varis, O., Biswas, A. K., Tortajada, C., & Lundqvist, J. (2007). Megacities and Water Management. *International Journal of Water Resources Development*, *22*(2), 377–394.

Varis, O., & Somlyódy, L. (1997). Global urbanization and urban water: Can sustainability be afforded? *Water Science and Technology*, *35*(9), 21–32. doi:10.1016/S0273-1223(97)00181-9

Vinck, D. (2003). *Everyday Engineering - An Ethnography of Design and Innovation*. The MIT Press.

WERF. (2009). *Using Rainwater to Grow Livable Communities - Stormwater Best Management Practices*. Retrieved from http://www.werf.org/liveablecommunities/studies_orlando_fl.htm

© ASCE 2014

Risk Assessment in Underground Rail International Construction Joint Ventures in Singapore

Bon-Gang Hwang, M.ASCE[1], Xianbo Zhao[2], and Gwendolyn Shiyun Yu[3]

[1] Department of Building, National University of Singapore, 4 Architecture Drive, Singapore 117566; PH (65) 6516-7488; email: bdghbg@nus.edu.sg

[2] School of Engineering and Technology, Central Queensland University, 400 Kent St, Sydney, NSW 2000, Australia; PH (61) 2 9324 5775; email: b.zhao@cqu.edu.au

[3] KPK Quantity Surveyor (Singapore) Pte. Ltd., 865 Mountbatten Road, Singapore 437844; email: yushiyun89@gmail.com

ABSTRACT

International construction joint ventures (ICJVs) have been widely used in large-scale infrastructure projects all over the world. Since the 1980s, Singapore has experienced the use of ICJVs in underground rail projects. This study aims to assess the risks associated with the underground rail ICJVs in Singapore. To achieve this objective, a comprehensive literature review was carried out, producing a list of 27 risks. Categorizing them into internal, external and project-specific risks, a questionnaire survey was conducted with 33 contractors to collect the likelihood of occurrence and magnitude of impact of risks, and using the data, risk criticalities of each risk were calculated. Based on the risk criticality values, risks were ranked within and across the three categories. The analysis result reported "disagreement on some conditions in contract" as the most critical risk. In addition, project specific risks obtained the highest risk criticality value. With the help of this study, ICJV partners can identify the most critical risks and thus develop risk mitigation measures. Also, the findings from this study provide a comprehensive picture of risks for the companies intending to participate in underground rail ICJVs in Singapore.

INTRODUCTION

Joint ventures (JVs) can be defined as the commercial agreement between two or more companies in order to allow greater ease of work and cooperation towards achieving a common aim, through the manipulation of the appropriate resources (Norwood and Mansfield 1999). An international construction joint venture (ICJV) is formed when two or more construction firms contributing their equity and resources to a construction project and at least one partner has its headquarters outside the country where the ICJV operates. With the growing scale and complexity of construction projects as well as the globalization, ICJVs have become one of the major organization forms widely used in large-scale infrastructure projects all over the world (Lin and Ho 2012).

In Singapore, the Mass Rapid Transit (MRT) construction, which commenced in the 1980s and is still in progress, requires high-level civil engineering technologies and a large amount of capital (Zhao et al. 2013). The Singapore government encouraged foreign firms to form ICJVs with local contractors to bid for such projects, which helped facilitate the development of local contractors. In the context of Singapore, underground works are very risky due to the complex and unpredictable ground conditions. Thus, it is difficult to control the ground settlement (Nakano et al. 2007) and its impact on built structures, which have been regarded as pressing issues in Singapore underground rail construction (Osborne et al. 2008). Also, the complexity of management and operation issues within ICJVs engender risks associated with disagreements, disputes and conflicts (Goh and Kwok 2000). Furthermore, ICJVs are also plagued with external risks that fall outside the control of companies (Frame 2003; Li et al. 1999; Low et al. 2009). As a result, stringent risk management is necessary and crucial to the participants of ICJVs in Singapore underground rail projects.

As underground rail construction will last till 2020 and contractors may form ICJVs to bid for these projects, it is meaningful for the practitioners to understand the risks in these ICJVs. The objectives of this study are: (1) to identify the most critical risks associated with performing underground rail ICJVs in Singapore; and (2) to examine the differences in risk criticality (RC) values and risk ranks between foreign and local contractors. RC values can be calculated using the likelihood of occurrence (LO) and magnitude of impact (MI) collected from a questionnaire survey. Thus, risks can be ranked and the most critical ones can be identified. Also, statistical analysis methods are used to examine the differences in RC values and ranks of risks between foreign and local firms. The recognition of critical risks is necessary and important for the contractors that are either participating or about to participate in ICJVs, regardless their company nationalities. Using the findings from this study, contractors can be clear about the risks that are critical for them, thus developing the mitigation strategies.

LITERATURE REVIEW

Previous studies have been conducted to identify the risks associated with ICJVs. For example, using a questionnaire survey, Kwok et al. (2000) found that the most important risks factors for ICJVs in Singapore were disagreement in accounting profit and loss, potential financial distress of partners, partner's lack of management competence and resourcefulness, over-interference by parent companies of either parties, and disagreement on allocation of works. In addition, Shen et al. (2001) identified 58 risks for the Sino-foreign construction JVs in Mainland China and reported cooperation with government offices, proper risk allocation in contract, and technical risk control as practical strategies to deal with them.

Through a comprehensive literature review, this study identified a list of 27 risks, as shown in Table 1. It should be noted that in addition to the risks common to ICJVs, there are risks specific to underground construction. The impact of settlement on built structures and ground settlement control appeared to be thorny issues in underground rail construction in Singapore (Osborne et al. 2008). With reference to Li et al. (1999), this study categorized risks into internal, external, and project specific risks. More specifically, internal risks arise from an ICJV itself and are unique because different organizations are involved, while external risks stem from the competitive macro environment where the ICJV operates. Project specific risks refer to unforeseen events that come from project characteristics and may affect the ICJV performance.

Table 1. Risks associated with underground rail ICJVs

Code	Risk	References									
		A	B	C	D	E	F	G	H	I	J
IR01	Policy changes in partner's parent company towards ICJV	*							*		
IR02	Partner's parent company in financial problems	*		*		*	*	*	*	*	
IR03	Over-interference by parent company of either partner	*		*					*		
IR04	Partner's lack of management competence and resourcefulness	*	*	*		*	*	*	*	*	
IR05	Distrust between partner employees	*		*			*	*			
IR06	Disagreement on allocation of staff positions in ICJV company or project team	*		*				*			
IR07	Disagreement on allocation of works	*		*			*	*			
IR08	Disagreement on accounting of profit and loss	*		*		*	*				
IR09	Technology transfer dispute	*		*	*	*	*	*			
ER01	Inconsistency in government policies, laws and regulations	*	*	*	*	*		*	*	*	
ER02	Labor, material and equipment import restrictions	*	*		*	*		*			
ER03	Restrictions on fund repatriation	*		*		*			*		
ER04	Economy fluctuation	*	*			*		*	*		
ER05	Inflation	*	*	*	*	*		*	*	*	
ER06	Exchange rate fluctuation	*	*	*	*	*		*	*	*	
ER07	Force majeure	*	*	*	*			*			
ER08	Pollution	*	*		*			*			
ER09	Language barrier	*						*			
ER10	Different social, cultural and religious background	*	*	*	*		*	*			
ER11	Security problems at project site	*	*		*			*		*	
PR01	Disagreement on some conditions in contract	*			*	*		*	*		
PR02	Client's excessive demands and variations	*	*					*			
PR03	Client's cash flow problems	*		*				*	*	*	
PR04	Poor relationship between JV team and client or consultant	*	*		*			*			
PR05	Incompetence of local subcontractors and material suppliers	*	*		*	*		*	*		
PR06	Ground settlement										*
PR07	Settlement control (structures)										*

IR=Internal Risks; ER=External Risks; PR=Project Specific Risks.
References: A=Li et al. (1999); B=Shen et al. (2001); C=Kwok et al. (2000); D=Jamil et al. (2008); E=Yeo (1995); F=Walker and Johannes (2003); G=Zhang and Zou (2007); H=Goh and Kwok (2000); I=Ahiaga-Dagbui et al. (2011); J=Osborne et al. (2008).

METHODOLOGY

© ASCE 2014

Data collection and presentation

Based on the literature review, a survey questionnaire was developed. The questionnaire consisted of questions that captured the profile of the respondents and those solicited the LO and the MI of the 27 risks, which were classified into external, internal and project specific risks. The questionnaires were sent out to the contractors with experience in underground rail ICJVs in Singapore and the efforts produced a total of 33 completed survey questionnaires from 33 contractors. As ICJVs in underground rail projects require massive investments and deep considerations to carry out, there were a limited number of contractors with the experience in such projects, which can partly explain the relatively small sample size in this survey. Despite the small sample size, statistical analysis could be carried out because the central limit theorem holds true when the sample size is over 30 (Hwang et al. 2013).

A summarized profile of the contractors is presented in Table 2. 57.6% of the respondents were from foreign firms while 42.4% were from local ones. In addition, most of the respondents were from the grade A1 (63.6%) and A2 (24.2%). Only 28.6% of the A1 respondents were local companies, implying that the majority of local contractors were relatively small in size. Also, in terms of the experience of the contractors, 57.6% of them took part in only one underground rail ICJV, while 42.4% had repeat ICJV experiences.

Table 2. Profile of contractors

Contractor profiles		Categorization	N	%
Foreign	Registry grades*	A1	15	45.5%
		A2	4	12.1%
Local	Registry grades *	A1	6	18.2%
		A2	4	12.1%
		B1	3	9.1%
		B2	1	3.0%
Experience of contractors**		1	19	57.6%
		2	12	36.4%
		3	2	6.0%

*BCA grading system: A1-unlimited tendering limit; A2-up to S$85 million; B1-up to S$40 million; B2-up to S$13 million.
**The number of underground rail ICJVs that a contractor had participated in.

Risk indices

The respondents were required to rate the LO and MI of each risk associated with underground rail ICJVs. The LO was rated according to a five-point scale: 1=rarely (LO < 20%); 2=somewhat likely (20% ≤ LO < 40%); 3=likely (40% ≤ LO < 60%); 4=very likely (60% ≤ LO < 80%); and 5=almost definite (LO > 80%). Also, the MI was evaluated using another five-point scale: 1=very small; 2=small; 3=medium; 4=large; and 5=very large. The LO and MI of each risk can be calculated using equation (1) and (2), respectively.

$$LO^i = 1/n \times \sum_j^n LO^i_j \quad (1)$$

© ASCE 2014

$$MI^i = 1/n \times \sum_j^n MI^i_j \quad (2)$$

where n = the number of the respondents; LO^i = the LO of risk i; LO^i_j = the LO of risk i by respondent j; MI^i = the MI of risk i; and MI^i_j = the MI of risk i by respondent j. Thus, the LO and MI of each risk are actually the mean scores assigned by respondents. This study also adopted a risk criticality (RC) index to evaluate the criticality of each risk. As RC has been recognized as the function of the LO and MI despite different terminologies (Fang et al. 2004; Shen et al. 2001; Sun et al. 2008; Zou et al. 2007), the RC of a risk can be computed as follows:

$$RC^i_j = LO^i_j \times MI^i_j \quad (3)$$
$$RC^i = 1/n \times \sum_j^n RC^i_j \quad (4)$$

where n = the number of the respondents; RC^i_j = the RC of the risk i by respondent j; and RC^i = the RC of risk i. Thus, RC is on a full scale of 25. Besides the overall RC of a risk, the RC of a risk can also be calculated using equations (3) and (4) based on the opinions of foreign and local firms, respectively. The RC of a risk is not the product of the LO and MI of a risk. Based on the RC values, risks can be ranked within and across the three categories, i.e. internal, external and project specific risks.

DATA ANALYSIS AND DISCUSSIONS

Intra-category risk ranking

Internal risk ranking

Table 3 presents the intra- and inter-category risk rankings. "Disagreement on accounting of profit and loss" (IR08) was the most critical internal risk factor. This high RC rank greatly resulted from its high LO and MI ranks. As a sensitive issue, sharing profits and losses between partners concerns the earnings of them. It is usually easy for the top management of each partner to solve minor disagreement on accounting of a profitable JV project. However, it would be difficult to overcome the disagreement over who should bear losses, once losses occur (Kwok et al. 2000).

"Distrust between partner employees" (IR05) was ranked second, which revealed that contractors emphasized the trustworthy relationship and the ability of their potential partners to manage projects. This risk also got a high LO rank and a high MI value, indicating that distrust within ICJVs was probable to occur and impactful on the performance of ICJVs. Selecting right and trustworthy partners to form an ICJV is a reasonable measure to mitigate this risk.

"Partner's lack of management competence and resourcefulness" (IR04) was seen as the third most critical internal risk. The result indicated that setting up an ICJV with a contractor with low-level management competence and resourcefulness was likely to greatly impact on ICJV objectives. Thus, the management competence and resourcefulness of partners should be emphasized by all the companies when they select ICJV partners.

"Over-interference by the parent company of either partner" (IR03) occupied the fourth position. Over-interference by parent companies shows low-level

© ASCE 2014

autonomy of partners, and can lead to low efficiency in decision-making in ICJVs, which would slow down the execution of projects and operation of ICJVs.

Table 3. Intra- and inter-category risk ranking

Risk category	Risk code	Index value			Risk ranking					
					Intra-category			Inter-category		
		LO	MI	RC	LO	MI	RC	LO	MI	RC
Internal risks (LO=2.95; MI=3.30; RC=9.80)	IR01	3.12	3.36	10.42	5	5	5	9	14	13
	IR02	2.03	3.70	7.58	9	1	7	24	5	18
	IR03	3.36	3.33	11.18	2	6	4	3	16	8
	IR04	3.15	3.67	11.61	4	2	3	7	7	5
	IR05	3.30	3.64	12.06	3	4	2	4	9	3
	IR06	2.79	2.70	7.36	7	8	8	15	23	19
	IR07	3.12	3.03	9.55	5	7	6	9	18	16
	IR08	3.39	3.67	12.48	1	2	1	2	7	2
	IR09	2.24	2.61	5.94	8	9	9	23	25	24
External risks (LO=2.63; MI=2.95; RC=8.13)	ER01	2.97	3.48	10.39	4	3	4	13	13	14
	ER02	3.18	3.76	12.00	2	1	1	6	4	4
	ER03	1.76	2.70	4.88	11	8	10	26	22	26
	ER04	3.27	3.33	11.09	1	4	3	5	16	9
	ER05	2.48	2.64	6.61	9	9	9	22	24	23
	ER06	2.55	2.58	6.70	7	10	8	20	26	22
	ER07	2.52	2.73	7.00	8	6	7	21	20	21
	ER08	2.70	2.85	7.76	5	5	5	16	19	17
	ER09	2.61	2.73	7.27	6	6	6	19	20	20
	ER10	3.09	3.61	11.58	3	2	2	11	10	6
	ER11	1.85	2.03	4.15	10	11	11	25	27	27
Project specific risks (LO=2.79, MI=3.70; RC=10.48)	PR01	3.52	4.06	14.33	1	1	1	1	1	1
	PR02	3.09	3.55	11.00	3	6	3	11	12	10
	PR03	1.61	3.33	5.33	7	7	7	27	16	25
	PR04	2.82	3.70	10.61	4	4	4	14	5	11
	PR05	3.15	3.61	11.39	2	5	2	7	10	7
	PR06	2.70	3.85	10.61	5	2	4	16	2	11
	PR07	2.64	3.79	10.06	6	3	6	18	3	15
Overall value		2.78	3.26	9.29						

Despite the low RC rank, "partner's parent company in financial problems" (IR02) merited attention because of its top MI rank. This result revealed that this risk would greatly impact ICJV, once it occurred. However, the bottom LO rank of this risk indicated that this risk factor was less likely to occur, probably because companies usually carefully check the financial status of their potential partners to eliminate this impactful risk. Finally, "technology transfer dispute" (IR09) got low LO, MI and RC values, implying that partners were comfortable with sharing technology, knowledge and experiences within the ICJV they set up.

© ASCE 2014

External risk ranking

As shown in Table 3, "labor, material and equipment import restrictions" (ER02) was ranked first, attributed to its high LO and MI ranks. In Singapore, a sudden restriction on imports of labor, material and equipment would disturb project construction as the supply of these resources mainly depends on imports. For instance, the recent increase in levy fees for Singapore work permit holders would result in a shortage of manpower in the construction industry (Hwang et al. 2013).

It was not strange that "different social, cultural and religious background" (ER10) occupied the second position. The high MI value indicated that it was impactful once it occurred. As there are contractors with various nationalities in the Singapore construction industry and an ICJV is comprised by partners from different countries, an ICJV in the Singapore construction industry is faced with various national cultures and organizational cultures and the consequent difficulties in cross-cultural communication. Thus, cross-cultural communication, cross-cultural dispute resolution, and cross-cultural negotiation (Low and Leong 2000) should be emphasized in ICJVs.

"Economy fluctuation" (ER04) was ranked third. An economic slowdown would cause the construction market to shrink, thus impacting the operations of construction firms (Adnan 2008). The high LO of this risk may be a result of the pessimism about the economy situation due to the 2008 financial crisis and the European sovereign debt crisis. The Singapore economy also slowed down in 2012 (Ismail 2012).

"Inconsistency in government policies, laws, and regulations" (ER01) obtained the LO value below 3.00, indicating that this risk was not highly likely to occur in Singapore. However, its high RC value showed that changes in government policies, laws, and regulations were still emphasized by construction firms. In addition, "security problems at project site" (ER11) got a very low RC score, confirming the good social security status in Singapore.

Project specific risk ranking

As shown in Table 3, "disagreement on some conditions in contract" (PR01) was the most critical project specific risk, attributed to its high LO and MI values. This revealed that this risk was very likely to occur and would have a large impact on ICJVs. Conflicts within an ICJV would eventually arise as the project proceeds, if there was disagreement on contract conditions. Such conflicts would destroy the partnership and threaten project objectives.

"Incompetence of local subcontractors and material suppliers" (PR05) obtained a high RC value resulting from the high MI value and high LO rank, implying that the consequence of this risk was perceived severe, although the LO value was not very high. Incompetence of subcontractors and suppliers tend to bring about low working efficiency, material supply delay, poor quality of works or materials, disputes, etc. Thus, uncertainties regarding the technical qualifications, timeliness, reliability, and financial stability of subcontractors and suppliers were worth great attention and it is recommended to use experienced and familiar subcontractors and suppliers (Li et al. 1999).

"Client's excessive demands and variation" (PR02) received the third critical position. Clients' demands and variation are common problems in construction projects, regardless of procurement methods. Such problems are usually associated with the change of work allocation among partners, the disruption of work, and claims (Li et al. 1999), thus resulting in disputes, conflicts, and threats to the ICJV performance and project objectives. This risk had a low MI rank but got a high MI value, indicating that the overall impact of project specific risks was at a high level.

The two risks related to technical problems, "ground settlement" (PR06) and "settlement control (structures)" (PR07) obtained LO values below 3.00. Such technical risks are common and general problems in underground rail projects and professional contractors are able to identify these obvious risks early in the project life cycle. Thus, such risks could be prevented from occurring and were perceived less likely to occur. However, once they occur, their impacts would be very large. In addition, "client's cash flow problems" (PR03) was ranked bottom, implying that the client have a strong cash flow. This was because the client of all the underground rail projects in Singapore is the Land Transport Authority (LTA), which is a statutory board under the Ministry of Transport of the Singapore Government.

Inter-category risk ranking

Risk factors were also ranked across risk categories based on their RC values (see Table 3). "Disagreement on some conditions in contract" (PR01) obtained the top LO, MI and RC values, and should be adequately emphasized by ICJV partners. The top rank of this risk echoed the viewpoints of Sridharan (1995) that a detailed JV agreement cannot guarantee a conflict-free partnership and that ICJVs with brief documents can also have less conflicts if partners trust and frankly communicate with each other.

The LO, MI and RC values of each risk category were the average of LO, MI and RC values of all the risk factors falling within this category, respectively. The overall LO, MI and RC values were the average of LO, MI and RC values of all the risk, respectively. As Table 6 indicates, internal risks got the highest LO value while project specific risks obtained the highest MI and RC values. External risks seemed less critical to ICJVs in underground rail projects in Singapore. As LO values of all the three risk categories were below 3.00, the likelihood of them was not high. In addition, the MI values of internal risks and project specific risks were above 3.00, revealing that these two categories significantly impacted ICJV performance. The overall LO, MI and RC values were 2.78, 3.26 and 9.29, respectively, indicating that risks in underground rail ICJVs in Singapore were at a slightly high level.

CONCLUSIONS

This research aims to assess the risks faced by partners in underground ICJVs in Singapore. A total of 27 risk factors, which were identified from literature review, were ranked using the proposed RC index. At the category level, project specific risks were the most critical. At the risk factor level, "disagreement on accounting of profit and loss", "labor, material and equipment import restrictions", and "disagreement on some conditions in contract" were the most critical risks in categories of internal, external, and project specific risks, respectively. Also, "disagreement on some

© ASCE 2014

conditions in contract" obtained the top LO, MI and RC values, indicating the great importance to achieve agreement in contract terms within an ICJV.

Despite the achievement of objectives, there were some limitations to conclusions that may be drawn from the results. First, as the sample size in this study was small, cautions should be warranted when the analysis results are interpreted and generalized. In addition, the method of analyzing RC in this study was highly subjective as it was influenced by the individual experience and risk attitude of the respondents. Lastly, the findings from this study were well interpreted in the context of Singapore but they may be also applicable to underground rail ICJVs in other countries. Nonetheless, with the help of this study, ICJV partners can identify the most critical risks and thus develop mitigation measures. In addition, the findings from this study provide a comprehensive picture of risks for the companies intending to participate in underground rail ICJVs in Singapore.

REFERENCES

Adnan, H. (2008). "An assessment of risk management in joint venture projects (JV) in Malaysia". *Asian Social Science*, 4 (6), 99-106.

Ahiaga-Dagbui, D. D., Fugar, F. D. K., McCarter, J. W., and Adinyira, E. (2011). "Potential risks to international joint ventures in developing economies: The Ghanaian construction industry experience." *Proceedings of the CIB W107 Conference on Innovation and Sustainable Construction in Developing Countries*, Hanoi, Vietnam, 191-196.

Fang, D., Li, M., Fong, P., and Shen, L. (2004). "Risks in Chinese construction market—Contractors' perspective". *Journal of Construction Engineering and Management*, 130 (6), 853-861.

Frame, J. D. (2003). *Managing Risk in Organizations: A Guide for Managers*, Jossey-Bass, New York, NY.

Goh, N. K., and Kwok, K. H. (2000). "*Management of Construction Joint Ventures*." Unpublished M.Sc thesis, Nanyang Technological University, Singapore.

Hwang, B. G., Zhao, X., and Ng, S. Y. (2013). "Identifying the critical factors affecting schedule performance of public housing projects". *Habitat International*, 38, 214-221.

Ismail, S. (2012). "*Economy likely to slow down in 2012: PM Lee*." Channel NewsAsia. <http://www.channelnewsasia.com/stories/singaporelocalnews/view/1178485/1/.html> (20 May, 2012).

Jamil, M., Ahmad Mufti, N., and Hassan Khan, A. (2008). "Risk identification for international joint venture construction projects." *Proc. of the 1st International Conference on Construction in Developing Countries*, Karachi, Pakistan, 291-301.

Kwok, H. C. A., Then, D., and Skitmore, M. (2000). "Risk management in Singapore construction joint ventures". *Journal of Construction Research*, 1 (2), 139-149.

Li, B., Tiong, R. L. K., Fan, W. W., and Chew, D. A. S. (1999). "Risk management in international construction joint ventures". *Journal of construction engineering and management*, 125 (4), 277-284.

© ASCE 2014

Lin, Y. H., and Ho, S. P. (2012). "The impacts of governance structure strategies on the performance of construction joint ventures". *Journal of construction engineering and management*, Doi: 10.1061/(ASCE)CO.1943-7862.0000619.

Low, S. P., and Leong, C. H. Y. (2000). "Cross-cultural project management for international construction in China". *International Journal of Project Management*, 18 (5), 307-316.

Low, S. P., Liu, J. Y., and He, S. Q. (2009). "External risk management practices of Chinese construction firms in Singapore". *Ksce Journal of Civil Engineering*, 13 (2), 85-95.

Nakano, A., Sahabdeen, M., Kulindran, A., and Seah, T. (2007). "Excavation management for slurry TBMs tunnelling under residential houses at C853 (CCL3) project." *Proceedings of Underground Singapore 2007*, Singapore, 38-45.

Norwood, S. R., and Mansfield, N. R. (1999). "Joint venture issues concerning European and Asian construction markets of the 1990's". *International Journal of Project Management*, 17 (2), 89-93.

Osborne, N. H., Hassell, C. K., Tan, L., and Wong, R. (2008). "A review of the performance of the tunnelling for Singapore's circle line project." *Proceedings of World Tunnel Congress 2008*, Agra, India, 1497-1508.

Shen, L. Y., Wu, G. W. C., and Ng, C. S. K. (2001). "Risk assessment for construction joint ventures in China". *Journal of Construction Engineering and Management*, 127 (1), 76-81.

Sridharan, G. (1995). "*Determinants of Joint Venture Performance in the Construction Industry: Cases from the Mass Rapid Transit Project in Singapore*." Unpublished Ph.D thesis, University College London, London.

Sun, Y., Fang, D., Wang, S., Dai, M., and Lv, X. (2008). "Safety risk identification and assessment for Beijing Olympic venues construction". *Journal of Management in Engineering*, 24 (1), 40-47.

Walker, D. H. T., and Johannes, D. S. (2003). "Construction industry joint venture behaviour in Hong Kong-designed for collaborative results?". *International Journal of Project Management*, 21 (1), 39-49.

Yeo, C. M. (1995). "*Risk Management in Construction Joint Ventures*." Unpublished M.Sc thesis, Nanyang Technological University, Singapore.

Zhang, G., and Zou, P. X. W. (2007). "Fuzzy analytical hierarchy process risk assessment approach for joint venture construction projects in China". *Journal of Construction Engineering and Management*, 133 (10), 771-779.

Zhao, X., Hwang, B. G., and Yu, G. S. (2013). "Identifying the critical risks in underground rail international construction joint ventures: Case study of Singapore". *International Journal of Project Management*, 31 (4), 554-566.

Zou, P. X. W., Zhang, G., and Wang, J. (2007). "Understanding the key risks in construction projects in China". *International Journal of Project Management*, 25 (6), 601-614.

© ASCE 2014

PIPE JACKING IN SPECIAL GEOLOGY OF TEHRAN CITY

Keivan Pakiman[1], Arash Jenabi[2], Payam Soltan Sanjari[3], Babak Mohammadi[4]

1- Executive Deputy site manager at Tehran Micro Tunneling Projects, Kayson Inc., Water & Wastewater Division, Iran, K.Pakiman@kayson-ir.com
2- Executive Deputy at Water & Wastewater Division, Kayson Inc., Iran, AJenabi@kayson-ir.com
3- Project Manager of pipe jacking projects, Kayson Inc., Water & Wastewater Division, Iran, Payams@kayson-ir.com
4- Member of Technical section at Tehran Micro Tunneling Project, Kayson Inc., Water & Wastewater Division, Iran, B.Mohammadi@kayson-ir.com

ABSTRACT

In this paper, performance of a slurry micro tunneling machine used for Tehran Sewage network project is presented. The total project route is 3855 meters and the polymer concrete pipes with 1400mm, 1600 mm and 1800 mm diameters are used in this project of which 56% has been completed up to now.

This paper introduces pipe jacking project during excavations in specific geological conditions which caused many obstacles. Some pipes were broken in different positions during crossing this specific geological condition and many problems created for the project facing huge stone. In addition, crossing hard and big boulder layers led to intensive damage for machine and cutter head and increased project implementation cost. In continue of crossing through this specific geological context, huge boulders in front of machine blocked the way completely and the project was forced to perform the remaining by the hand shield method. Also performing handmade tunnel has new obstacle that project team pass through step by step. In this paper all obstacles reviewed by considering sustainability parameters and increasing sustainability of pipeline is mentioned in any part of project to find the best way in crossing impossibilities. This project shows real challenges to find a best way for solving the obstacles of such micro tunneling projects until the contractor succeed.

INTRODUCTION

Nowadays, with the aid of progressive science and technology, some new technologically developing methods are utilized in order to construct infrastructures for new megacities all around the world. Machine technologies have taken the place of man power within these advanced methods and construction of megacities has been justified efficiently. Pipe jacking method provides some advantages as one of the increasingly using methods that are listed as follow:

- Minimizes disturbance in the cities, the least traffic jam.
- Avoids infrastructure damage due to the least soil disturbance.
- Crosses through highly important roads, highways, rivers and canals.

© ASCE 2014

- Decreases total cost.
- Increases construction rate, the more safety.
- Create Environmental advantages.

ENVIRONMENTAL AND SUSTAINABILITY ADVANTAGES

This modern method benefits has more environmental and sustainability advantages than the traditional method as it brings an increasing interest toward using the method. There are some advantages of the modern method as follows:

– Higher life cycle and durability of concrete polymer pipes against wastewater corrosion so it provides higher pipeline sustainability.
– Using the separation plant in order to recover water from the slurry line and collecting the extra urban soil which leads to environmental pollution reduction.
– Using environmental friendly and recyclable pipes for wastewater projects.
– Using high compression resistance pipes increases the sustainability against collapses or immediate consolidation.
– Less traffic jams because of less road occupation which leads to less environmental pollution and noise.
– Safe transmission below urban infrastructures increases the sustainability of urban infrastructures and saves them from any probable destruction.

PROJECT SPECIFICATIONS REVIEW

PROJECT OVERVIEW

Tehran comprehensive sewage network plan has been operated in almost all areas of the city in recent years. Two operating projects of Kayson Inc. have been located in northeast and west part of the city.

The project includes operation of main transmission sewage lines by pipe jacking method. Pipes diameters in the northeast project are 1400, 1600 and 1800 mm with the length of 551, 2170 and 1175 meters respectively. The pipe diameters in the western project are 1600 and 1800 mm and the length are 4200 and 600 respectively. In the followings, some problems during pipe jacking operation in the east project are reviewed.

GEOLOGICAL CONDITION

From the geological point of view, site is located on very dense alluvium layers with a wide range of rock lenses sorted from silt stone to giant boulders. Moreover, Tehran is located on quaternary geology. Tehran alluvium has been emerged from sedimentation of some large rivers which led to existence of huge boulders and anisotropic sediments of soil layers. On the other hand, because of too old history of Tehran, encounter with old buildings and wastewater storages during pipe jacking operation is inevitable.

© ASCE 2014

Figure 1- Main sewage network

The precise geological review is necessary to provide sustainability requirements such as performing pipeline in stable layers and secure crossing into other infrastructures without causing any settlement. To take the geological importance of the project into consideration, the geotechnical investigations have been done at the first phase of the project. Table 1 and figure 1 Show geotechnical properties of the soil and an overview of the project:

Table 1- Geotechnical properties of project

Line	Bulk Density ton/m^3	Cohesion Kg/cm^2	Friction Angle	E-Gpa	Rock Compressive Strength(Mpa)	Rock Tensile Strength(Mpa)
A-B	1.95-2.12	0.15	39	100-120	200	19.2
	1.89-2.06	0.25	36	50-75	200	19.2
B-C	1.97-2.13	0.21	38	100-120	200	19.2
C-D	1.94-2.11	0.23	37	100-120	200	19.2
E-D	1.92-2.09	0.2	37	35-50	200	19.2
G-F	1.85-1.95	0.1	45	100-120	200	19.2

PIPE JACKING OPERATION FROM SHAFT NUMBER 49 TO SHAFT NUMBER 50

Since the project line connected to Tehran's main sewage transmission tunnel at its lowest zone, the project implementation started from this zone using pipes of 1800mm in order to expedite sewage network exploitation. Of total 1176 meters, 875 meters was operated successfully using pipe jacking method in an appropriate geological condition and undisturbed soil. However, the remaining part met barely

© ASCE 2014

seen and geologically special soil fabric. Figure 2 Shows pipe jacking route between shafts numbers 49 and 50 with 97 meters distance and shafts number 49 and 48 with 92 meters distance. Further, as presented in figure 4, a particular soil layer as shown in figure 3 with very dense boulder layers started from 10 meters east of shaft number 49 until 15 meters west of shaft number 48. The density of boulder layer increased moderately from east to west reached the maximum near shaft number 48.

Figure 2- 1800 mm pipe line route in Khaje Abdollah street

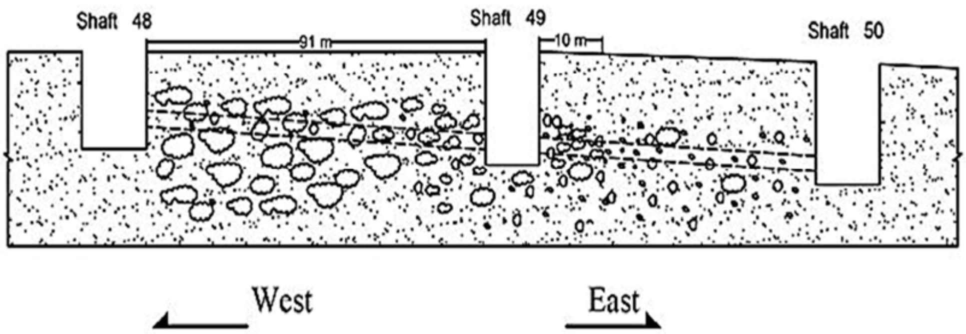


Figure 3- Special Geology

PIPE JACKING OPERATION FROM THE SHAFT NUMBER 49 TO THE SHAFT NUMBER 50

When the cutter head encountered excessive cut-offs, pipe jacking operation got into trouble between the shafts number 49 and 50. Further investigations revealed that the high number of cut offs were due to the cutter head collision with its very dense boulder layer. Another problem occurred when steel cuttings were observed in the device hydraulic oil during periodic oil test which confirmed severe hydro motor damage. The first actions were to repair the damaged machine and reinvestigate the ground condition. As shown in the figures 4a & 4b, the visual survey of the tunnel determined the boulders as the main reason of hydro motor damage.

Figure 4-a- Ground type in line 49-50

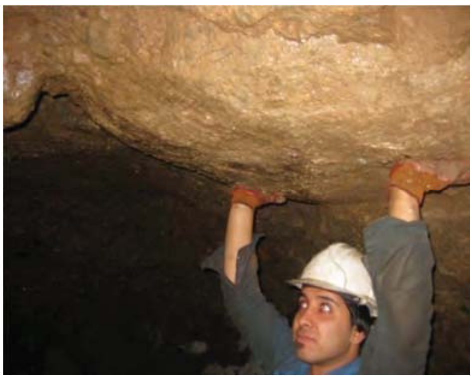


Figure 4-b- Boulder size at the beginning of line 49-50

A new hydro motor was replaced by the damaged one simultaneously because of unsuccessful hydro motor repairing. Nevertheless, the giant boulders were broken and removed from the tunnel. Fortunately soil fabric turned to the sandy soil after approximately 10 meters of excavation and remained unchanged until receiving the shaft.

Figure 5-a- details of damaged hydro motor

Figure 5-b- Repairing the hydro motor

Beside unsuccessful efforts of hydro motor repairing, the new device was replaced by the damaged one in order to develop the excavation progress. Figures 5a & 5b show damaged hydro motor and repairing process respectively.

PIPE JACKING OPERATION FROM THE SHAFT NUMBER 49 TO THE SHAFT NUMBER 48

CUTTER HEAD DAMAGE

To cope with the problems explained in the previous section, the cutter head cutting tools were renewed and refreshed. However, these new cutting tools didn't show enough toughness and durability to withstand the huge size boulders. The pipe jacking operation was performed with low efficiency rate until pipe number 10 for so many blocking that occurred. Figure 6 shows broken pieces of the nails and rollers in slurry line.

© ASCE 2014

Figure 6-Broken piece of nails and rollers in slurry line

PIPE BREAKAGE AND REPLACEMENT

The pipe number 10 in the middle of the line broke suddenly due to a giant boulder drop when pipe number 17 was being performed in (figure 7a & 7b). The dimension of the damaged part was 40×60 cm approximately. The reason and probable improvement was studied through the applied hole in the pipe. So for increasing sustainability of pipeline it was necessary to demolish the pipes separately and support the boulders by building a special steel frame. Therefore pipes were destroyed step by step and pipe remnants and rock were removed before pipe jacking started again.

Having destroyed the damaged pipe in a four-level procedure, the overhead boulder was removed according to figure 8. Before this, the geotechnical soil properties were fully investigated to ensure the short time (during digging and inserting pipe line) soil stabilization and sustainability of ground for long term parameters after pipeline operation was finished.

Figure 7-a- Crack in pipe

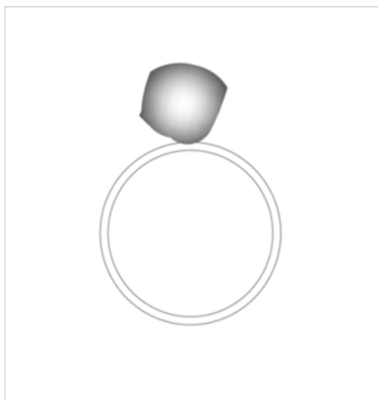


Figure 7-b-pipe Breakage by boulders

The long term sustainability is very important because both of ground settlement around the pipe line and probable open spaces affect seriously the pipe line life cycle.

© ASCE 2014

Moreover, Tehran cemented soil provides higher strength than other similar soil types. It is noticeable that the underground water level was far below the pipe jacking operation level so there was no concern about the water seepage into the line or reduction in the soil stabilization that increases sustainability of pipe line from operation time and durability point of view.

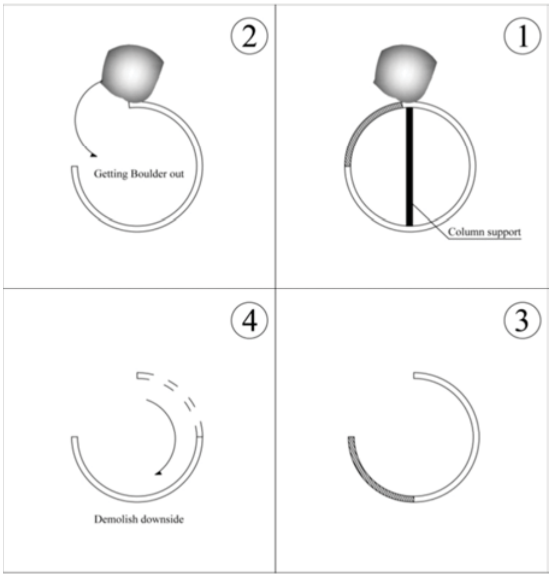


Figure 8- Pipe breakage and removing

At the first, the upper side of the pipe was protected by a steel column. The second level was to destroy the left top section of the pipe which was not engaged to the boulder. This increases the operation safety because we can protect the manpower from any probable boulder movement hazard. At this level, the boulder can be removed. Thereafter the down left section of the pipe was broken and removed. This is perquisite to get the intact right side pipe to freely be rotated. Finally the upper side soil tension is released by a clockwise pipe rotation and is broken up and removed easily.

CRUSHER CONE DAMAGE

Slurry line was blocked after performing 60 meters layer. According to these blockings, we had to check out any probable fault. So after opening the frontal window, ground condition as well as crusher cone were investigated carefully. It was determined that the device was severely eroded in a harsh collision with too much dense boulders which caused an enlargement in entrance openings of crusher cone (fig 9). This allows the openings to pass larger particles into the slurry line so exceed the standard limitation and blocked it.

© ASCE 2014

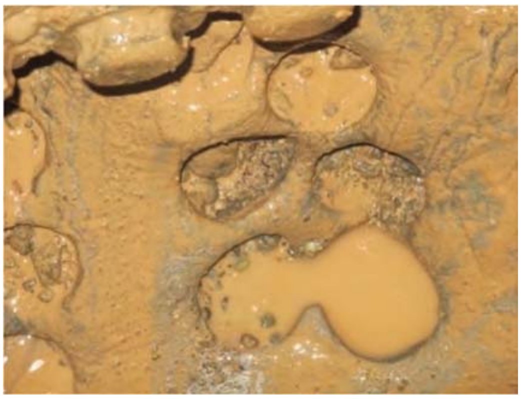


Figure 9-Crusher cone holes

In order to fix the problem some practical solutions were proposed. But underground welding was another issue. As an appropriate alternative, as shown in figures 10a & 10b, particular rings were designed and put into the dilated openings to decrease to their original size. The pipe jacking operation resumed after the welding and crushing core repair completion in the entrance opening section.

Fig 10-a- design of ring

Fig 10-b- Repairing crusher cone holes by ring

FORCE MACHINE OPERATION STOP BY A GIANT BOULDER

Although the first 72 meters of the pipe jacking were applied with difficulty, the operation ceased for the remaining part because a giant boulder blocked the way.

Through 72 meters on the route from the shaft number 48 to the shaft number 49, the pipe jacking operation stopped due to non- progressive excavation and high hydraulic jack pressure. So the device frontal opening was opened and the ground condition was controlled during numerous surveys. A huge boulder observed after the window was opened and it was responsible for the problems which led to stop the operation. Figure 11 shows the dimension of the boulder.

© ASCE 2014

Figure 11-Huge boulder in front of machine

The following methods were proposed after various investigations:

1- Construction of Rescue shaft and removing boulder

2- Destruction of the bolder

3- Digging the hand shield tunnel for the rest 20 meters from the reception shaft toward the machine.

According to the acquired geological data, the rescue shaft method was rejected because the probability of similar incidents occurrence is very high and construction of many rescue shafts was not economical.

Figure 12-a-Huge boulderssizes

Figure 12-b-Excavation by hand through huge boulders

On the other hand, the limited available space in front of the machine would not provide the feasibility of the boulder destruction. So the hand shield tunneling method as a reasonable and practical option was opted to reduce further operation risk for the rest 20 meters (figure 12). Nevertheless there were unpredictable

© ASCE 2014

challenges in the mentioned tunneling route. This issue has been described in the following.

OLD WASTE WATER STORAGE

In addition to the high density and large dimensions of the boulders, there was old wastewater storage at the middle of the handmade tunnel. Figures 13 and 14a and 14b show the location and also details of the old waste water storage.

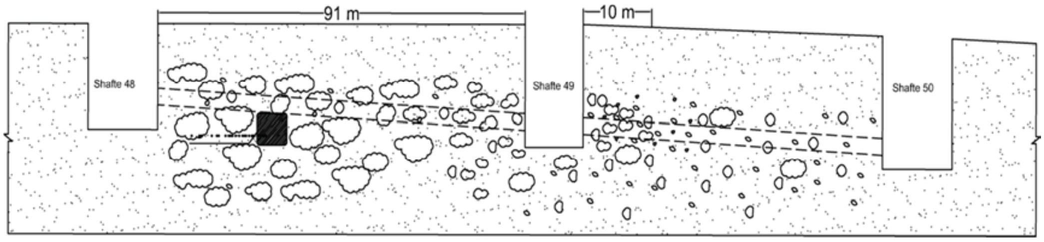


Figure 13-Waste water storage location

Figure 14-a-Waste water storage

Figure 14-b-Waste water sorage

The wastewater storage was blocked immediately when the storage was investigated and the entrance flow rate was calculated carefully. Thereafter it was necessary to protect the machine and other accessories. So the wastewater storage was filled by available boulders and special bags filled by soil and limestone to ensure about sustainability of pipe line and ground around this wastewater, Then the hand shield excavation continued to reach the machine (fig 15).

Finally, dimensional enlargement operation of the tunnel was performed to provide adequate space for pushing the machine. To ensure that heavy 30-ton machine could transit safely thorough the wastewater storage and more sustainability of pipeline during operation time an enforced concrete slab was designed and implemented on the storage floor of the excavation way to the reception shaft.

© ASCE 2014

Figure 15-crossing machine through handmade tunnel

PIPES CRACK DURING MACHINE TRANSIT IN THE HAND SHIELD TUNNEL

The second pipe of the last three driven pipes from the drive shaft cracked longitudinally when the machine was being pushed to the hand shield tunnel (fig.16). The initial studies brought about no specific results, because the machine jack pressure was in the standard zone and the frontal section of the cutter head worked freely. Then the pipe was removed from the tunnel.

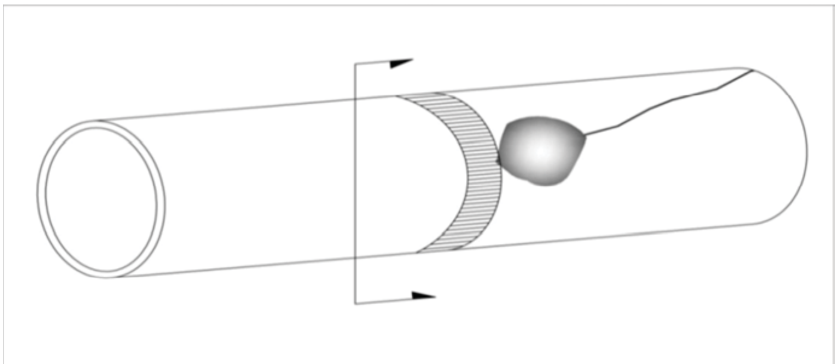


Figure 16-crack of pipe by boulder

The ground survey demonstrated that the caught medium size stone between pipe joints caused the pipe breakage. The stone was removed and the pipe jacking operation resumed again. According to figures 17a and 17b, the machine cutter head was damaged and the whole rollers and nails were eroded. The total operation cost picked up dramatically to 1.4 times the similar pipe jacking projects.

Figure 17-a- Damage of Cutter head in facing boulders

Figure 17-b-Damage of Cutter head in facing boulders

LESSONS LEARNED

1. Pipe jacking in rock increases the operation cost dramatically compared to other types of the soil.
2. Control of jack pressure and keep it in low ranges helps the safe device transit during driving into the rock type.
3. Bentonite injection especially during driving into rock layers reduces rock- pipe friction and increases operation efficiency and totally creates more sustainability for pipeline in counter with rock layers. Also bentonite lubricates the space between pipe and rock/soil layer that reduces rock material interactions and eventually reduces the particle blocking in the slurry line.
4. It is important to remove the non- level sections in the joints or make them level (leverage) before the pipe jacking operation is started, since the boulders get stuck in the space between the pipe joints.
5. The existence of opening in machine seems very useful to control the ground condition hazards especially during driving in rock layers.
6. Anti-abrasion welding or installations of particular tools which are eroded before the main devices are very effective to avoid the crusher cone erosion in rock layers.
7. In some cases with dense rock, the hand shield tunneling seems more beneficial compared to the pipe jacking method. By using hand-shield method we can observe and investigate ground situation and soil properties and eventually more consideration on sustainability parameters.
8. Lines in which the unpredictable obstacles such as old waste water storages are available, checking the deviations should be in priority to create more sustainability in pipe line execution. On the other hand, when the hand shield tunneling is used, the protection shelter is a necessity for manpower against probable rock fall.
9. Omitting or modifying horizontal and vertical pipe line deviations plays a significant role in improvement of sustainability parameters and also a considerable increase on pipe line operation time. Pipe line execution into rock

© ASCE 2014

layers and facing sump pits increase the deviations which seriously threaten the pipe line sustainability.

REFRENCES

1. Barth Florian and J. Frosch Robert (2001). "Control of cracking in concrete structures" , ACI 224R-01
2. M. Das Braja (1941). "Principles of Foundation Engineering"
3. M. Leet Kenneth & Uang Chai-Ming (2002). "Fundamentals of Structural Analysis"
4. M. Shahabi and K. Pakiman (2012). "Tehran sewerage pipeline project via pipe jacking method, 1st No-dig Berlin 2013 conference
5. (1998). "Pipe made of filled polyester resin molding materials", DIN 54815-2
6. (2005). "Standard specification for polymer concrete pipe", ASTM D 6783
7. (2010). "Technical documentation of Polymer concrete pipe", Concrete Polymer Pipe Company, Iran
8. (2008). "Herrenknecht AG manual", AVN1200TC
9. (2013). "Herrenknecht AG manual", AVN1600AC

© ASCE 2014

Overcoming Barriers to Implement Sustainable Street Lighting While Using Another Project's Mitigation Measures in North Park San Diego

René A. Vidales, PE, LEED Green Assoc, ENV SP, STP, M.ASCE

County of San Diego, 5510 Overland Ave. Suite 410, San Diego, CA 92123, PH (858) 694-3246; FAX (858) 495-5263; email: rene.vidales@sdcounty.ca.gov

ABSTRACT

When a master planned community's mitigation measures required implementation in an adjacent community, that community weighed in as to how those measures would actually be put in place.

A community-driven design took more than two years to take shape at monthly public community planning group meetings (many of which included the developer and some of which included City staff). The community applied many sustainability principles in the project design, including multi-modal connectivity between communities. The installation of pedestrian-scale lighting was one of the most prominent and community-advocated project features.

The implementation of the project's pedestrian-scale acorn lights became a challenge when City maintenance was not available due to a technicality in the City's maintenance contracting (i.e. the acorn lights were deemed an ornamental feature and not a City standard). Also, the street's location was outside of the nearest Maintenance Assessment District (MAD) boundary. Therefore, the City requested that the project proponent install the cold and unsophisticated looking standard "cobra" style light fixtures ubiquitous in today's urban landscape.

The community was persistent, and the developer was patient enough to successfully navigate through the City's complicated planning, design, and permitting process. Ultimately, the resilient neighborhood triumphed and got the acorn style lights installed using a creative maintenance financing mechanism, and thus maintaining the neighborhood's civil and aesthetic pride.

NORTH PARK AS A LOCAL LEADER IN SUSTAINABILITY

After experiencing decades of blight, North Park received a period of redevelopment centered around its historic "Main Street" in the mid 2000's. The community of North Park in San Diego, CA has since become a local leader in instituting sustainability practices in public infrastructure projects and private development. Those practices include an open-source sustainability plan *(North Park Main Street Sustainability Study and Implementation Plan, 2011)*, with strategies and interventions to be used by businesses and residents; crafting new policy into the first Sustainability Element of any Community Plan in the City of San Diego; the first community to include light pollution language in its Community Plan; and creating what will be the first Eco-District in the San Diego region.

© ASCE 2014

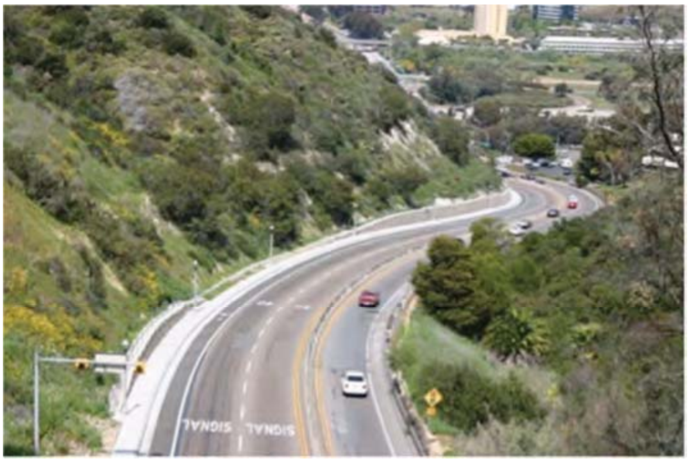


Fig. 1. View of Texas Street from Adams Avenue following improvements

NORTH PARK'S COMMUNITY PLANNING GROUP

San Diego's Planning Department bases much of what it does on the City's General Plan, which consists of overarching Elements that determine growth, development and land-use policies, and also contains specific guidelines for the 50 different community planning areas the City is divided into. Each of these areas has unique needs and desires, and therefore a locally elected community planning board was created in each of the planning areas to represent its residents and to serve as the City-recognized advisory body for their respective communities. The North Park Planning Committee (NPPC) is the officially recognized community planning group for the North Park planning area.

THE DISTANT PROJECT AND ITS MITIGATION MEASURES

In 2008, a developer proposed a Master Planned Community called "Quarry Falls" (later renamed Civita), located more than a mile away from North Park's northern border. This project comprises of 4,780 residential units, nearly 1.0 million square feet of retail & office/business park uses, and 31.8 acres of parks, civic uses, open space and trails. A project of this magnitude is typically built in phases.

The Civita project's Program Environmental Impact Report (PEIR) *(Quarry Falls {Civita} Program Environmental Impact Report, 2008)* disclosed traffic impacts to North Park requiring mitigation. The suggested mitigation included road widening along Texas St. through historic residential areas and sensitive canyons (Fig. 1, 2)

Widening the residential section of Texas Street (from a two-lane road to four-lane road) would have eliminated residential parking on both sides of the street, and widening the road northbound, along the non-residential section of Texas Street (from one lane to two lanes) would have encroached into canyons within environmentally sensitive lands. Due to these constraints, the impacts were considered "unmitigable" unless a partial mitigation solution could be found and agreed upon between the community, the developer, and the City.

© ASCE 2014

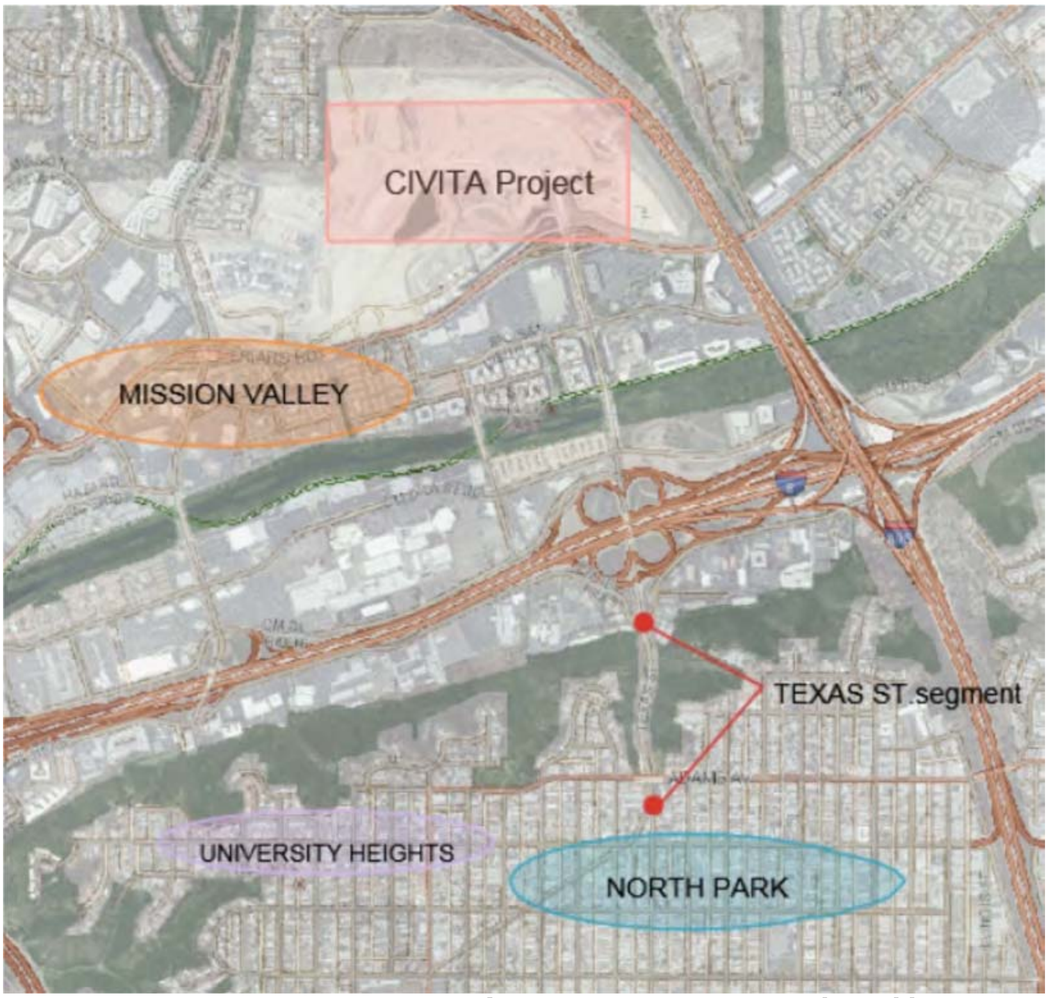


Fig. 2. Texas Street segment in relation to Civita project and neighboring communities

HOW ANOTHER PROJECT'S MITIGATION MEASURES BECAME NORTH PARK'S PROJECT

The community of North Park opposed the idea of widening Texas St. (for the sole purpose of adding traffic lanes to be used only by automobiles) as being inconsistent with community goals of sustainability, historic preservation, community character, pedestrian orientation and bike friendliness. Instead, the community identified the impacted ½ mile non-residential segment of Texas St. as having no bike lanes, no sidewalks, no lighting and thus not a safe bike or pedestrian connection between the communities of North Park and Mission Valley. This segment was considered hazardous for both pedestrians and bicyclists due to the steep grade and limited path of travel adjacent to the roadway. The road also did not have lighting or storm drain infrastructure within this neighborhood entry corridor and was therefore especially hazardous at night and during inclement weather.

And so North Park's project was born. The community embraced the opportunity to apply sustainability principles by suggesting previously non-existent features be added such as curb & gutter, a sidewalk, bike lanes, historically accurate pedestrian-scale lighting, drainage and storm drain facilities, hardscape elements, a

© ASCE 2014

graffiti-resistant retaining wall, and a community entry sign; instead of simply widening the street for the sole purpose of accommodating vehicular movements.

INITIAL ACTIONS BY THE NPPC ON THE PROJECT

The project was first heard at the NPPC Public Facilities subcommittee meeting on May 1, 2008 where the following motion was made:
"Developer to present a Traffic Calming option that would include a gateway element to the North Park Community along Texas Street, from Camino Del Rio South to Madison Avenue, with an option for the community to incorporate additional input into the plan." *(Meeting Minutes, Public Facilities subcommittee of the North Park Planning Committee, 2008-2011b)*

The NPPC met on August 19, 2008 and made a motion that included the following language:

"Whereas the 1986 Community Plan *(Greater North Park Community Plan, 1986)* called for the widening of Texas St., the 2002 North Park Public Facilities Plan *(Public Facilities Financing Plan for Greater North Park, 2002)* contains language that the North Park Planning Committee feels the widening of streets produces more traffic which is not desired in the community;

Whereas the traffic volume impact of the Civita Master Plan will result in approximately an 11 percent increase that was not anticipated in the 1986 Community Plan and the 2002 North Park Public Facilities Plan;

Whereas the existing 'k-rail' median is visually unappealing and detracts from the historic architectural character of North Park when better aesthetically pleasing options exist;

Therefore, the current North Park Planning Committee updates its modification to include, but is not limited to, 'k-rail' median replacement along with streetlights, underground utilities and sidewalks. The design and location of said 'k-rail' median replacement, street lighting, and sidewalks will be the result of input from community workshops and appropriate stakeholders, and at an amount not less than six million dollars ($6,000,000);

Therefore, be it resolved the current North Park Planning Committee requests the Planning Commission and City Council to incorporate the updated modifications as Conditions of Approval to be installed at Civita at developer expense in addition to a 500,000 dollar contribution for miscellaneous traffic calming and related measures as mitigation for project related traffic volume increases in North Park." *(Meeting Minutes, North Park Planning Committee, 2008-2011a)*

Based on input from the NPPC and mitigation measures listed in the Final PEIR, the Civita project had the following language in its Conditions of Approval:

"Prior to the issuance of any building permits for Phase 1, applicant shall assure by permit and bond, the implementation of the following traffic calming measures on Texas Street from El Cajon Boulevard to Camino Del Rio South: provide pedestrian lighting and a new sidewalk from Camino Del Rio South to Madison Avenue [per item T4 in the Greater North Park Planning Committee's Priority List on page 13 of the Public Facilities Financing Plan (*Public Facilities Financing Plan for Greater North Park, 2002)*], and contribute $100,000 (2007 dollars) in funding for traffic calming to be determined by the community from

© ASCE 2014

Madison Avenue to El Cajon Boulevard." *(Mitigation Monitoring and Reporting Program, Quarry Falls {Civita} Program Environmental Impact Report, 2008)*

ALTERNATIVES PRESENTED ON ACORN STYLE PEDESTRIAN LIGHTS

The developer of Civita presented several different alternatives for project features at numerous public workshops at the NPPC Public Facilities subcommittee in 2010, including different types, styles and finishes of retaining wall, hardscaping elements, and options for acorn style pedestrian lights. The community was excited to be able to participate in the selection of project specific features, as this was a rare opportunity.

One of the particular project features was the pedestrian lighting component, for which there were several options of acorn style lights. Inspired by early 20th century aesthetics, the brand selected for the acorn lights had increased efficiency to reduce energy usage, was one of the most recent innovations in the field of exterior lighting, and with its light engine, was considered one of the most environmentally responsible luminaires available.

The project was not only going to be a great enhancement to the community, but also a sustainable and environmentally friendly one, due to the new connectivity between the North Park and Mission Valley communities by providing a new walking and bicycling route along with pedestrian lights.

At the July, 2010 Public Facilities subcommittee meeting, there was consensus from the group to use acorn lights for pedestrian lighting similar to existing light fixtures in the North Park portion of El Cajon Boulevard (double acorn lights) and University Avenue (single acorn lights). Double acorn lights are usually installed in higher traffic areas similar to El Cajon Boulevard. The type of lighting that had been reviewed and approved by the City for installation in public right-of-way was single acorn 'Serenade DSX Series IES cutoff' as shown in the cut sheets presented by the developer and shown on the lighting plan (Fig. 3). During the meeting the following motion was made:

"To recommend light fixtures matching the aesthetic character of the El Cajon Boulevard lighting fixtures, but as a single acorn light in the color 'textured dark forest green', with the provision that the applicant comes back with a visual presentation." *(Meeting Minutes, Public Facilities subcommittee of the North Park Planning Committee, 2008-2011b)*

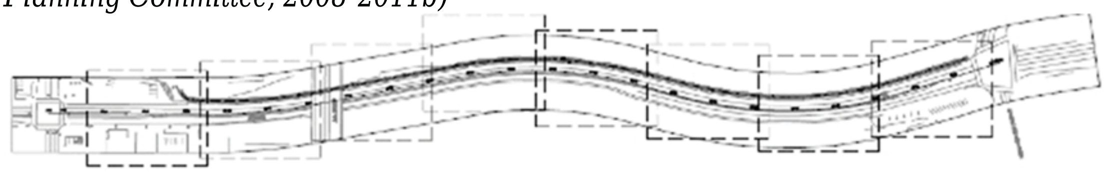


Fig. 3. Lighting Plan of the 2010 project

BARRIERS TO IMPLEMENT SUSTAINABILITY IDENTIFIED

The Texas Street project was located outside of the boundaries of both the North Park Maintenance Assessment District (MAD) *(Engineer's Report for North Park Maintenance Assessment District, 2013a)* and the proposed Civita MAD *(Assessment Engineer's Report for Civita Maintenance Assessment District, 2013b)*. The North Park MAD did not cover any areas north of Monroe Avenue within the

© ASCE 2014

North Park community and the Civita MAD would only cover the project boundaries within the Mission Valley community.

Due to the lack of an enhanced maintenance funding mechanism, the City ruled out the neighborhood's chosen pedestrian-scale (acorn style) lighting component, and instead specified standard street (cobra style) lights, because their maintenance was covered under the City's standard maintenance budget from the general fund for public streets.

At the August, 2010 Public Facilities subcommittee meeting, it was revealed that the Deputy Director of Development Services Department (DSD) would not support the installation of acorn lights without a MAD. The City's Street Design Manual *(Street Design Manual, 2002)* stated that "Supplemental street lighting for ornamental, continuous street lighting, or pedestrian-scale lighting purposes, shall be installed in street lighting assessment districts. Street lighting assessment districts will be formed only upon the request of the properties which will be included in the district."

The community made the argument to DSD that since existing acorn lights were a historic precedent since the 1920s and part of the community character, that this should supersede the language in the Street Design Manual which was geared for new development projects and not existing communities that were over 125 years old. The argument was ultimately successful.

At the NPPC meeting held on August 17, 2010 the following motion was made:

"Whereas the mitigation measures outlined in the Civita Project MMRP (*Mitigation Monitoring and Reporting Program, Quarry Falls {Civita} Program Environmental Impact Report, 2008),* requires providing pedestrian lighting on Texas Street;

Whereas single acorn lights are ordinarily specified for pedestrian lighting, Cobra lights are ordinarily specified for roadway projects and the lighting to be placed on Texas Street is only for pedestrians;

Whereas the earliest acorn lights in the North Park community are from the 1920s, allowances should be made to incorporate lighting consistent with that existing in the neighborhood, and compatible with the historic nature of the North Park community;

Whereas there is City precedent for matching new architectural elements to existing historic resources that do not meet current regulation (whether or not they are in a historic district);

Whereas there is consensus between developer and community on selecting the single acorn light and there was also consensus with City staff for several months after holding several meetings, the NPPC requests that the Mayor reject this last-minute decision to deny single acorn lights for the Texas Street pedestrian improvement project and to direct the DSD to approve the Civita/NPPC agreed-upon proposal." *(Meeting Minutes, North Park Planning Committee, 2008-2011a)*

OVERCOMING BARRIERS TO IMPLEMENT SUSTAINABILITY

Undeterred, North Park lobbied for and insisted on pedestrian oriented historical and aesthetically pleasing lighting consistent with the North Park's goal to

© ASCE 2014

be more pedestrian friendly. The developer had generously agreed to pay for the higher cost of the acorn lighting even though this was not a City or a mitigation requirement, and the community was unwilling to lose the benefit of the developer's generosity. The acorn lights proposal included more frequent light posts for the lower intensity pedestrian lighting than for the higher intensity cobra lighting, therefore raising the construction cost of the project.

Even though there were more acorn lights than cobra lights being proposed within the subject area of Texas Street, the acorn lights would not consume more electricity. Maintenance for acorn lights would be a little more expensive than cobra lights due to the uniqueness of the product.

The following was discussed at the September, 2010 NPPC Public Facilities subcommittee meeting: The developer had to change the original agreed-upon project improvement plans to remove the acorn lights and replace them with cobra lights in order for the City to approve the project; the change in the type of lights meant changing the number of poles because more frequent light posts were required for the lower intensity pedestrian lighting than for the higher intensity Cobra lighting. The change in the plans subsequently changed the retaining wall design around the poles. The driver for the lighting change was that the Civita project schedule required approval at the City Council meeting to meet one of their financing milestones. However, several City staffers were supportive of the acorn lights, including the Councilmember representing North Park.

The following was disclosed at the November, 2010 Public Facilities Sub-committee meeting: NPPC board members met with a senior advisor on the Mayor's staff and with the Councilmember with regard to the proposal to install acorn lights in an area without a MAD. The Parks and Recreation Department staff person in charge of all the MADs in the City was willing to explore finding another way to add the acorn lights into the project. In addition, the senior advisor to the Mayor was about to leave his job at the City and the process was likely to become delayed.

THE ENDOWMENT FUND

NPPC came up with the idea of setting up an endowment fund. The following points were drafted in order to be included in the City's agreement to cover management of the Fund.

<u>Names/Terms</u>: Texas Street Endowment Fund ("the Fund"); North Park Planning Committee (NPPC); Maintenance Assessment District (MAD)

$100K in mitigation funding from the Civita project is intended to be used as an Interest Bearing endowment fund for enhanced maintenance on Texas Street (the Fund).

The interest income from the Fund is to be used to cover only those maintenance costs over and above the City standard [delta]. Currently that would cover costs above City standard incurred by the decorative acorn lighting.

As there was no MAD in place on Texas Street, the City would pay for whatever the standard maintenance would be for the standard "cobra" lighting; the Fund would pay only the difference (delta) between standard maintenance for standard lights and enhanced maintenance for acorn style lighting

© ASCE 2014

Should the interest income from the Fund be insufficient to cover the maintenance expenses (delta) in any year, the principal may be used.

During a meeting on February 07, 2011 between NPPC members and City officials, it was made clear that the interest on the Fund might not be sufficient for all maintenance costs required, so the NPPC motion deliberately did not limit the use of principal as and when required. It was the intent of the NPPC board to husband this unusual resource as best possible, to ensure it would last as long as possible, and to provide the best "bang for the buck" for the community.

In the event that a MAD be put in place on Texas Street, the best further use and disposal of any balance still remaining in the Fund should be determined by public meeting and vote of the NPPC Board.

It was a possibility that either the North Park MAD or some other form of MAD may eventually (at some point in the more distant future) be put into place to cover Texas Street. In this eventuality, the intent of the NPPC was to ensure that any balance remaining in the Fund did not automatically get subsumed by a new MAD, but that the remaining balance be able to be used by the community (NPPC) for whatever enhancements Texas Street may require at that future date. The impacts from the Civita development on Texas Street would be more apparent once the development was fully built-out, and the community thought those future mitigation needs might not be limited solely to maintenance, but could include other traffic calming, street enhancement, beautification, or mitigations yet unforeseen. The NPPC motion deliberately did not limit or specify the possible uses of any remaining fund balance, as they felt that a future NPPC board should have discretion to determine needs at that time.

The Fund should be able to be added to, by fundraising or any other means, particularly if no other form of maintenance funding is to be put in place for Texas Street.

The City was clear that, should the Fund run out of funds before other maintenance funding was available, the City would reserve the right to remove the decorative acorn lighting and replace it with standard lighting. However, if additional capital could be added to the Fund such that the interest alone would pay for the enhanced lighting maintenance, then the Fund could operate in perpetuity.

Should the Fund be depleted down to a remaining balance of only ten thousand dollars, the City reserves the right to remove the acorn lights and replace them with City standard cobra lights, using the remaining balance for this purpose.

All of the above was discussed and agreed to during the February 7, 2011 meeting with the City. The following was not determined: which City Department manages and draws upon the fund and what will be the mechanism for reporting back to the NPPC annually on the balance and expenditure of the Fund.

LAST STEPS

Once the Endowment Fund Agreement was drafted, the NPPC held a meeting on February 15, 2011 and made the following motion:

"To approve developer mitigation improvements on Texas Street to include graffiti-resistant Keystone retaining wall, standard width sidewalk with 6-inch decorative border, xeriscape landscaping featuring cobblestones and boulders, 16

© ASCE 2014

single-globe acorn lights, $100K to be deposited into an interest-bearing endowment account with the City of San Diego for maintenance and utility costs over-and-above [delta] the City Standard, with the balance of the endowment fund to be refunded to the community when a permanent funding source for the costs becomes available; and to authorize the chair of the NPPC to execute agreements with the City of San Diego necessary to implement the improvements." *(Meeting Minutes, North Park Planning Committee, 2008-2011a)*

At this time, City officials were still not clear whether pedestrian lighting constituted traffic calming as stated in the project's conditions of approval. This lead to numerous editing of the contract language required to accept deposit of the funds for the traffic-calming project as provided by Civita.

Following months of delays while the issue was resolved, on May, 2011 the $100,000 for mitigation was finally deposited into an interest bearing account with the City. On June 21, 2011 the NPPC met and made a motion:

"With regard to the Texas Street enhancements maintenance endowment fund, the NPPC considers the currently proposed pedestrian enhancements, including specialty acorn pedestrian lighting, to constitute traffic calming as specified in the MMRP (*Mitigation Monitoring and Reporting Program, Quarry Falls {Civita} Program Environmental Impact Report, 2008),* for the Civita project" *(Meeting Minutes, North Park Planning Committee, 2008-2011a).*

The construction plans were revised yet again to remove the cobra lights and replace them with neighborhood preferred acorn style lights (Fig. 4). This changed the number of light poles and once again changed the design for the retaining wall around the power poles. The construction plans showed that the proposed acorn style lights properly illuminated the pedestrian and bike lane components of the project.

Construction on the project began in late 2011. The project was completed in January of 2013.

Fig. 4. View of an acorn style pedestrian light on Texas Street

BARRIERS TO IMPLEMENT SUSTAINABILITY CAME DOWN

The project's ribbon cutting ceremony was held on March 12, 2013. During the ceremony, the Chair of the NPPC thanked her predecessor, who devised a solution to funding the maintenance of the pedestrian lighting; the Chair and Vice-Chair of the Public Facilities subcommittee were also recognized for the extensive

© ASCE 2014

public meetings held to determine community preferences. She acknowledged the tenacity of the University Heights Historical Society and the communities of North Park and University Heights for never giving up. Lastly she thanked the City Councilmember (who was at that time Council President) for staying involved for facilitating solutions to the number of myriad obstacles that came up.

The Council President stated that "Texas Street is a primary link between District Three and Mission Valley, and the new sidewalk and other amenities improve safety and access" *(District 3 Dialogue, News from Council President Todd Gloria, 2013)*. He further stated: "The neighborhoods of North Park and University Heights will be well served by these improvements, and I personally appreciate the addition of a safe, active transportation element between these communities and Mission Valley" (*New sign welcomes travelers to Uptown neighborhoods, 2013)*. (Fig. 5)

Fig. 5. At the ribbon cutting ceremony: Mark Radelow (vice president and senior project manager of Sudberry Properties, developer of Civita); Pat Grant (member of Grant Family, which owns the Civita property and contributed to the improvements); Rob Steppke (former Chair of the NPPC); Alan Grant; René Vidales (Vice-Chair of the NPPC); Mary Grant, Vicki Granowitz (Chair of the NPPC); Dionné Carlson (Chair of the Public Facilities subcommittee of the NPPC); San Diego City Council President Todd Gloria; Marco Sessa (senior vice president of Sudberry Properties)

The lighting component of the project was consistent with North Park Main Street's Sustainability Plan, which was released later that year *(North Park Main Street Sustainability Study and Implementation Plan, 2011)*; the use of pedestrian-scale lighting was one of the many strategies contained in the plan. The Texas Street project was later nominated for Circulate San Diego's 2013 Urban Project Award *(Circulate San Diego, 2013 Golden Footprint Awards, Nominees, 2013).* The Civita land development project won ASCE's 2013 Outstanding Project Award for Region 9 in the category of Urban/Land Development Project *(ASCE Region 9 Awards, 2013 Outstanding Project Awards, 2013).*

CONCLUSION

There were four key ingredients in the overall success of the project, which included using a creative maintenance funding mechanism: 1) A flexible and

© ASCE 2014

transparent developer; 2) A vocal community planning group with strong civic advocacy; 3) A senior advisor on the mayor's staff that supported the community's vision over City policy and bureaucracy; 4) A City Councilmember who provided strong leadership by facilitating transparent communications and solutions among City staff, the Mayor's office, the developer and community members.

A tedious and lengthy process was worthwhile in the end. There is now a safe, attractive and well lit pedestrian and bike route on Texas Street where there was not one previously (Fig. 6), proving that the public, developers, City staff and politicians can work together to do great things.

The final project met the needs of the developer, the City, and most importantly the community, as it exemplifies the economic, social, and environmental principles of sustainability. A project that was conceived out of mitigation measures from impacts due to a community master plan, while increasing connectivity between communities it also improves the economic prosperity of both communities (North Park and Mission Valley). The end result also has social benefits as it connects people between communities, and environmental benefits by promoting walkability and bicycle activities while reducing light pollution and greenhouse gases.

APPLICABILITY TO OTHER AGENCIES

Outdoor lighting is important as an element of safety by illuminating sidewalks, roadways and community gathering spaces. Properly designed lighting systems can also promote an appreciation for a place at night.

As integral parts of the community, sustainable infrastructure projects should address individual comfort, health and mobility. Physical safety of users should be insured while light pollution should be minimized. Alternative modes of transportation should be encouraged and projects should be incorporated into the larger community mobility network. Further, infrastructure should ensure equal access to all.

Creative maintenance funding mechanisms for sustainable infrastructure projects are a great addition to any agency, as is implementing light pollution reduction measures by using lights only where necessary. In addition, other agencies can benefit by using a process to document, identify and baseline sustainability practices.

Fig. 6. Views of Texas Street from Adams Avenue

REFERENCES AND BIBLIOGRAPHY

ASCE (2013), *Region 9 Awards, 2013 Outstanding Project Awards* http://www.asce.org/Regions-Sections-Branches/Region-9/Awards/2013-Award-Recipients

© ASCE 2014

Circulate San Diego (2013), *2013 Golden Footprint Awards, Nominees*, http://www.circulatesd.org/get-involved/events/events-archive/2013-annual-gala-and-kaiser-permanente-golden-footprint-awards

City of San Diego (2013), *District 3 Dialogue, News from Council President Todd Gloria*, http://www.sandiego.gov/citycouncil/cd3/pdf/news/2013/dialogueapr13.pdf (April 2013)

City of San Diego (2002), *Street Design Manual*, http://www.sandiego.gov/planning/programs/transportation/library/stdesign.shtml

City of San Diego (2002), *Public Facilities Financing Plan for Greater North Park*, http://www.sandiego.gov/facilitiesfinancing/plans/northpark.shtml

City of San Diego (1986), *Greater North Park Community Plan*, http://www.sandiego.gov/planning/community/profiles/greaternorthpark/

EFS Engineering (2013a), *Assessment Engineer's Report for North Park Maintenance Assessment District, Fiscal Year 2014*, City of San Diego, http://www.sandiego.gov/park-and-recreation/pdf/aer/2014/14northpark.pdf (May, 2013)

EFS Engineering (2013b), *Assessment Engineer's Report for Civita Maintenance Assessment District, Fiscal Year 2014*, City of San Diego, http://www.sandiego.gov/park-and-recreation/pdf/aer/2014/14civita.pdf (March 2013)

North Park Planning Committee (2008-2011a), *Meeting Minutes, North Park Planning Committee*, http://www.northparkplanning.org/archive.html

North Park Planning Committee (2008-2011b), *Meeting Minutes, Public Facilities subcommittee of the North Park Planning Committee*, http://www.northparkplanning.org/archive.html

San Diego Uptown News (2013), *New sign welcomes travelers to Uptown neighborhoods*, http://sduptownnews.com/new-sign-welcomes-travelers-to-uptown-neighborhoods (March 15, 2013).

State Office of Historic Preservation (2011), *North Park Main Street Sustainability Study and Implementation Plan*, http://issuu.com/npeco/docs/sustainability_study_and_implementation_plan

Various Authors (2008), *Quarry Falls (Civita) Program Environmental Impact Report*, http://www.sandiego.gov/planning/community/profiles/missionvalley/pdf/quarryfallseir1pgs1thru178.pdf (July, 2008)

Various Authors (2008), *Mitigation Monitoring and Reporting Program, Quarry Falls (Civita) Program Environmental Impact Report*, http://www.sandiego.gov/planning/community/profiles/missionvalley/pdf/quarryfallseir3pgs491thru630.pdf (July, 2008)

© ASCE 2014

Coming to Grips with Project-Level NEPA as a Barrier to Sustainability, and Ideas for the Future

Richard L. Record[1]

[1]RL RECORD LLC *Consultants in Transportation, Infrastructure and the Environment*, 700 West Pete Rose Way, STE 463, Cincinnati, Ohio 45203; PH (513)744-9777; FAX (513) 744-9778; email: rrecord@rlecord.com

ABSTRACT

Despite the broadly-based effort for expanding sustainable outcomes on the transportation and infrastructure front, long established regulations and "ways" often run contrary to the desired outcome. One of the biggest offenders in this category is, surprisingly, the National Environmental Policy Act of 1969, or NEPA: not as it was written in law, but how it has come to be promulgated, administered and practiced, especially at the project level. On projects large and small, well-intended "environmental clearance processes" so firmly in place and having their root in NEPA are often significant hindrances to moving the sustainability success meter, and can skip right past untapped empowering opportunities that would provide significant net sustainability benefit. It is curious how closely related NEPA and sustainability are related philosophically and how far apart they often exist in practice

This paper speaks to how NEPA and all its subcategories (all the way down to the "permit" level), intended to protect and enhance the environment, often are applied unknowingly to the contrary, and makes suggestions about what might be done to make the NEPA a better performer on the sustainability front.

INTRODUCTION

The National Environmental Policy Act of 1969, or *NEPA* as it is commonly known, is widely recognized as one of the most far-reaching, elegantly crafted and broadly effective legislative actions in modern U.S. history, and is the linchpin of most environmental protection efforts related to federal actions, whether a highway project, a dam removal, or a rangeland management program. How is it then that NEPA, well-intended, inarguable, good-for-everybody NEPA, often stands in the way of bringing next-level sustainability into reality on projects and actions large and small? This paper briefly examines some of the framework and dynamics that contribute to this paradoxical relationship, and ideas to lessen NEPA's "barrier effect" in the future of sustainability.

© ASCE 2014

While NEPA applies to all public projects, actions or decisions by any federal agency, from the Department of Agriculture to the Department of the Army, this paper is oriented toward a Department of Transportation[1] perspective. NEPA plays a big part in all DOT actions[2], and the sustainability "next-level" potential in the world of transportation is a front-and- center issue of paramount importance today.

LEGISLATIVE AND REGULATORY CONTEXT

Starting January 1, 1970, NEPA brought two levels of consideration to the living room of infrastructure projects: 1) long-term/big-picture context and expectations, and 2) methods, documentation and accountability in decision-making, all targeted at environmental outcomes. The lay focus we see today is often on "impacts" under NEPA (as in Environmental *Impact* Statement), but that was never the full intent of the Act: the benefits side of the equation in any action is expressed and implied as just as important in the matrix of decision considerations. Unfortunately, from the very beginning, the primary promulgated[3] emphasis was on impacts, as in adverse impacts, and categorical impact avoidance, as the principal measure of success in compliance with NEPA. In many ways, the emphasis has changed very little over the almost 45-year life of NEPA.

This has big implications for the sustainability-NEPA relationship.

SUSTAINABILITY AS FRAMED WITHIN NEPA

The words "sustainable" or "sustainability" are not specifically found within the text of NEPA. However, Sections 101 and 102 of the Act put the key pieces in place for what we understand today as "sustainability"; for example (from §101,102):

- "…create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic and other requirements of present and future generation…"
- "…attain widest range of beneficial uses…"

---

[1] Including the Federal Highway Administration, Federal Transit Administration, Federal Railroad Administration, Federal Aviation Administration and Federal Maritime Administration.
[2] It is commonly held that a primary driver behind the original Act was catastrophic adverse impact outcomes from the early days of the interstate highway program under the Bureau of Public Roads (now FHWA) in the 1950's and 60's.
[3] NEPA established the Council on Environmental Quality within the President's Executive Office with oversight and regular reporting responsibility for the Act. CEQ issued directives to all federal agencies for promulgation of the legislative requirements, and each agency established (and continue to update and maintain) a regulatory framework for NEPA compliance.

© ASCE 2014

- "…insure that presently unquantified environmental amenities and values…be given appropriate consideration…along with economic and technical considerations."

It is clear in NEPA and the subsequent CEQ regulations that a balanced [sustainable] outcome is the goal, giving comprehensive consideration to all elements of the natural and man-made environment in long-term stewardship context. There is no mandate that impact avoidance should be the priority perspective or unequivocally take precedence over a balanced outcome. However, in NEPA practice at the project level, impact avoidance is often Job #1, even when additional impacts might actually contribute to a significantly improved sustainability outcome.

RECENT ARTICULATIONS OF SUSTAINABILITY IN TRANSPORTATION

The Transportation Research Board of the National Academies (TRB), U.S. transportation's primary research organizations in technical practice, has no fewer than twelve committees and task forces dealing with sustainability as a core issue[4]. Perspectives on definitions of sustainability within the TRB community vary, as is also the case in the larger transportation community. Two TRB research publications tell in part the recent evolutionary story in sustainability perspective.

In 2011, TRB issued a guidebook in sustainability performance measurement for transportation agencies (TRB, 2011). This item offered a brief description of sustainability and contributing social, environmental and economic elements tied by an "equity" expectation. But it also suggested that definition of sustainability be best left to individual transport agencies, state or otherwise, and concentrated on pathways and methods for adopting some sort of sustainability framework, however defined. In revisit of this 2011 piece, it somewhat has the flavor of ill-defined urgency; i.e., *sustainability is the new "it" thing and everybody's doing it, and here is how you can get on board.*

Just recently (May 2014) TRB released a more expansive and strategic look at sustainability in transportation agencies (TRB, 2014). One important, if not direct, finding in this work was that only fully-defined "triple bottom line" (TBL) sustainability approaches, optimizing for economic, societal and environmental outcomes, will provide the ROI potential that will allow transportation agencies to embrace sustainability within business case conditions fundamental to agency and program management. This is important evidence of new expectations, based in management and economics, being formalized and integrated on the sustainability front.

---

[4] Many other organizations U.S. and abroad also deliberate the sustainability question as it relates to transportation and other infrastructure, including the American Society of Civil Engineers, the American Association of State Highway and Transportation Officials, the International Road Federation, the Water Environment Federation, and the World Bank.

© ASCE 2014

THE EVOLVING EDGES OF NEPA

Over the past 4+ decades, and despite the big picture sustainability charge established in Sections 101 and 102, NEPA has grown somewhat long in the tooth and comfortable in a "managed" approach within many agencies.

In 2010, TRB's *Environmental Analysis in Transportation* Committee undertook an internal and peer group survey to help identify evolving "edges" within the NEPA framework.

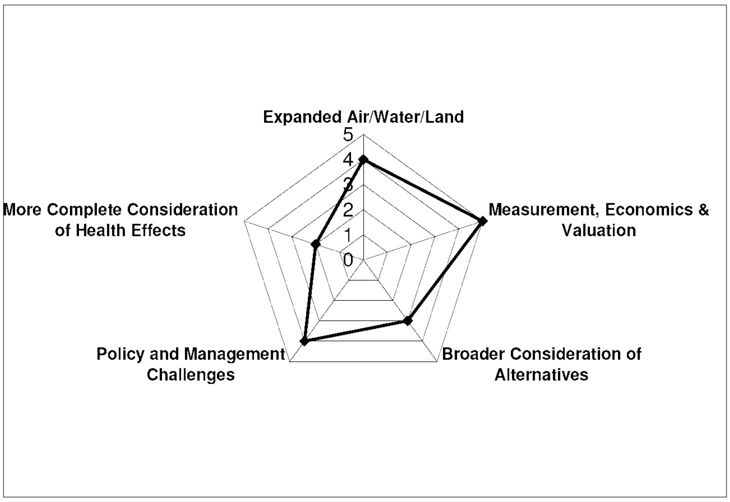


Figure 1 - *Emerging edges in NEPA, as identified by TRB's Environmental Analysis in Transportation Committee (Transportation Research Board, 2010)*

The key findings, graphically represented[5] in **Figure 1** (above) and described briefly below, have held up well over the past four years as on-target and indicative of the changing trends in environmental analysis and NEPA:

- **ExpandedAir/Water/Land**: a more complete understanding of action consequences and relationships across physical regimes.
- **Measurement, Valuation and Economics**: more complete quantification, valuation of resources and benefits or disbenefits, and economic treatment.
- **Broader Consideration of Alternatives**: more complete consideration of operational and management alternatives, including no-build/low-build; intermodal relationships and effects.
- **Policy and Management Challenges:** outcome effects, analysis demands and reporting challenges due to increased funding dynamics and policy shifts.

---

[5] The spider chart plot represents relative frequency of reported "edge" groups at time of survey.

© ASCE 2014

- **More Complete Consideration of Health Effects:** better understanding and reporting on human health effects, including safety.

What we see from this array is confirming of much of the recent work in sustainability in the U.S. and internationally, and it also confirms the important role of NEPA and its very powerful but underemphasized Sections 101 and 102 in understanding and delivering practicable, valuable and perhaps enforceable sustainability efforts.

"PERMIT" VERSUS INTENT: JUST THE WRONG APPROACH?

Despite its broad articulations of sustainability fundamentals, and despite all good agency intentions, NEPA at the project level typically takes on more of a "permit" function and flavor, with analysis actions and avoidance efforts targeted at discrete groups of impact categories, and particularly weighted toward those with special legislative or regulatory status (no matter how deaf the special status to the local context). In line with a permit treatment, it is predictably common for the phrase "we got it cleared" to be carried into project level NEPA discussions, again, as the primary measure of success.

Lost, or at least well subdued, in all of this is the Section 101/102 intent of NEPA. When a project's environmental focus is pushed toward, for example, minimizing acres of wetland, or avoidance of a 404 permit, as primary measures of NEPA compliance, and in that process misses an important and valuable (in balance) environmental enhancement or sustainability opportunity, the real intent of NEPA is stepped on in an unfavorable way.

In best practice, NEPA is just as much a project design element as a bridge pier foundation, or a highway lighting plan. And such a "design" approach is critical to effective integration of total sustainability[6].

MOST ACTIONS ARE BELOW RADAR

A confounding part of trying make NEPA work harder and more cost-effectively in support of sustainability in project delivery has to do with the administrative and procedural framework of the environmental process as it has evolved. Most projects under NEPA are small actions. The vast majority of transportation projects, for example, in the U.S. each year are not major actions of great impact, or that are required to go under NEPA review at the broadly circulated and scrutinized Environmental Assessment (EA) or Environmental Impact Statement (EIS) level. Most are "processed" at the Categorical Exclusion (CE) level, often utilizing a standard template framework. CE's are typically not as robustly developed and are certainly not as broadly circulated and scrutinized EA or EIS level NEPA work.

---

[6] We define "total sustainability" to be synonymous with a balanced and reconciled (under NEPA) triple bottom line sustainability condition.

© ASCE 2014

While a good argument can be made that a CE is no less robust than any EA or EIS, just of different scale or intensity, and, although a CE must account for all the components expressed by the Act, the analysis and reporting (and *expectation*) is typically limited.

The irony is that while the greatest total potential (by far) for accrued total sustainability benefit is found within the category of thousands of CE-level projects evaluated under NEPA each year[7], the CE level procedure is not so friendly to a thorough examination on that front. While there are certainly near-term efficiencies in compact and standardized NEPA examinations and procedures, CE or otherwise, the long term benefit stream of *refinement for total sustainability* goes untapped, unless solidly examined and translated from committed prior planning.

EXAMPLES OF THE "BELOW THE RADAR" GAP

The transportation industry is rife with these examples of disconnects with NEPA intent and sustainability opportunity. Here are two real-world examples (with DOT names omitted to protect the well-intended); both examples look at energy consumption/fuel use as a primary dominant indicator, but any of many other indicators could be inserted and assessed for sustainability outcome (human health, net economic productivity, water resource and ecosystem value, etc) for these or other projects:

- A south-central state delivered a minor side road intersection realignment improvement and new signal control on a 30,000 Average Daily Traffic major suburban arterial (and Federal highway) as a Categorical Exclusion 1 with essentially no reported impacts, as only two property takes were required; an "easy" environmental processing. But in this easy path, the signalized intersection was required to be located at the bottom of a vertical curve sag on the major arterial, extending to grades in excess of 4% and 1,500 feet in each direction, requiring significant new expenditure of energy by mainline traffic for downgrade braking and upgrade acceleration under signal control. The net new energy input required was in excess of 100,000 gallons of fuel annually (and additional operating costs of $0.4 million per year assigned to drivers). But in a total sustainability approach, side road realignment to a more energy-favorable intersection location on a mainline grade vertical curve crest might have been considered. Although it might require five disturbed property takes, one relocation, a mitigable Section 404 permit, a higher level of CE processing, and, importantly, an additional $1.6 million in capital, it would provide a much more defensible long-range outcome, and would be

[7] Even impact-benign minor intersection improvements, processed at the lowest CE level under NEPA, have room within project mission to accommodate a total sustainability examination at the project level.

© ASCE 2014

cost-neutral within 5 years and cost-positive beyond. This alternative was not examined under NEPA.

- A Midwest state with a high truck volume east-west interstate highway needed to add a lane and shoulder width each direction to a long, low multi-pier structure traversing a broad low-gradient river and associated floodplain. To avoid environmental complications and assure "easy" processing, the work was conducted by necking down the traffic to one lane each direction for the 18 month project duration, and constructing the bridge widening from the topside (no river or floodplain work), rather than new parallel structures and maintenance of capacity during construction. The project was processed as a low-level CE, but the cost was more than 20 million gallons of truck diesel fuel alone due to delays during construction, all to avoid a more comprehensive NEPA path that could have addressed largely mitigable river system impacts and avoided significant irreversible expenditure of carbon resources. This alternative was screened out as not prudent under NEPA.

In each case, the desire for few NEPA complications, often ironically and perhaps incorrectly called "streamlining", resulted in project-level decisions *that were actually bad in the total sustainability picture in at least one major indicator category*, and could be argued were not truly consistent Sections 101 and 102 of the Act. In each case, any planning-level examination was not of sufficient detail, was not seen by the right set of "eyes", or was not carried through in project-level hand-off and translation to mitigate any disconnect between NEPA procedures and sustainability outcomes. These and thousands of other CE-level transportation actions come forward each year "below the radar" of total sustainability[8]. Other projects may be "too big to see" on key NEPA accountability issues (Transcend Consulting Group, 2009).

THE REEMERGENCE AND IMPORTANCE OF PLANNING, AND BUMPS ALONG THE WAY

From the original Act, NEPA always anticipated and encouraged a strong role for effective planning in meeting the balance mandate in its requirements; the language is there. Lack of tools and diverted attention had pushed the planning component to the background in many decades of NEPA's life; most focus was on project-level execution, outcomes, and crisis management.

---

[8] While the focus here has been on CE-level NEPA executions, the same types of disconnects can and do occur in EA and EIS-level actions, less frequently by simple arithmetic of occurrence of EA and EIS filings, but potentially of greater individual scale and consequence.

© ASCE 2014

In recent years, USDOT and FHWA have refreshed and reemphasized the role of planning (**Figure 2**). More effective NEPA consideration of projects, especially complex projects with a "balance" question or opportunity, is part of the agency perspective and expectation in this Planning-Environmental Linkages (PEL) effort.

Integrated planning of this type is a valuable tool in the quest for total sustainability at the project level, and has been part of the success package for some notable outcomes on the environmental and sustainability front. But, even when in place, it is not a complete or even appropriate answer to the gaps we see today at the project level.

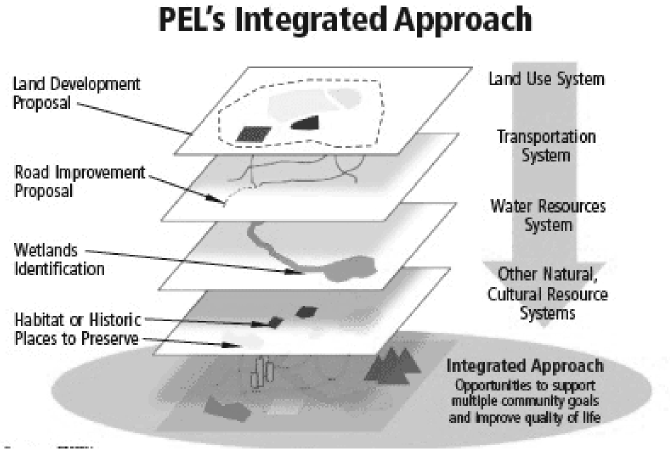


Figure 2 - *FHWA is ramping up its efforts to better integrate planning in NEPA examinations, an important part of an effective total sustainably platform (illustration: FHWA, in Berberio, et al, 2008)*

WHERE ARE THE SUSTAINABILITY OPPORTUNITIES IN THE CONTINUUM OF PROJECT DELIVERY?

Continuing with the planning discussion, it is important to recognize, in simple terms, where the sustainability opportunities are found in the timeline continuum of project concept to end-of-useful-life. The short answer is, sustainability opportunities are everywhere, in every stage (**Figure 3**, below).

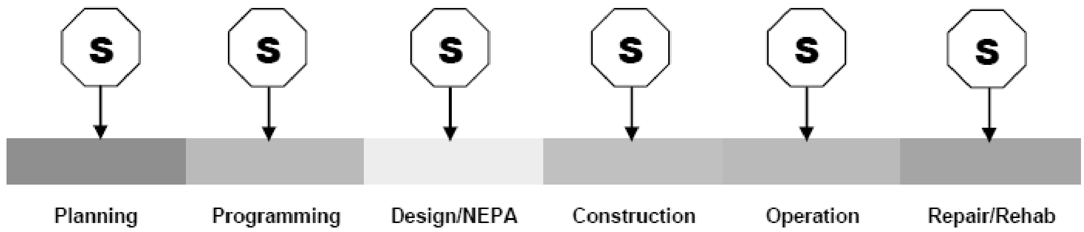


Figure 3 - *Sustainability insertion opportunities are found in every stage of a project, from concept to end-of-life*

Two important things not readily evident in Figure 3 need to be emphasized:

© ASCE 2014

1. In transportation, the potential for greatest sustainability "effect" or benefit is found in three general areas: Planning/Programming, Design/NEPA, and Operation.
2. Achieving total sustainability typically requires effort and action at every stage.

The tools, authorities and administrative practices affecting a sustainability effort in project delivery vary widely, even within one agency or program. This is a significant challenge for the future and "next-level" sustainability.

WHAT DOES CURRENT PRACTICE ACTUALLY LOOK LIKE?

When we think about how sustainability efforts and elements actually come into place in the life history of projects, it is anything but a steady-state situation. Typically, there are great swings in potential effect, strength of support, administrative accommodation, and level of attention. In the midst of this, equipped with a potentially powerful mandate supporting a total sustainability outcome, and grounded in federal law, is NEPA.

Figure 4 (below) illustrates the complexities of sustainability potential and opportunity over the life of a typical transportation project:

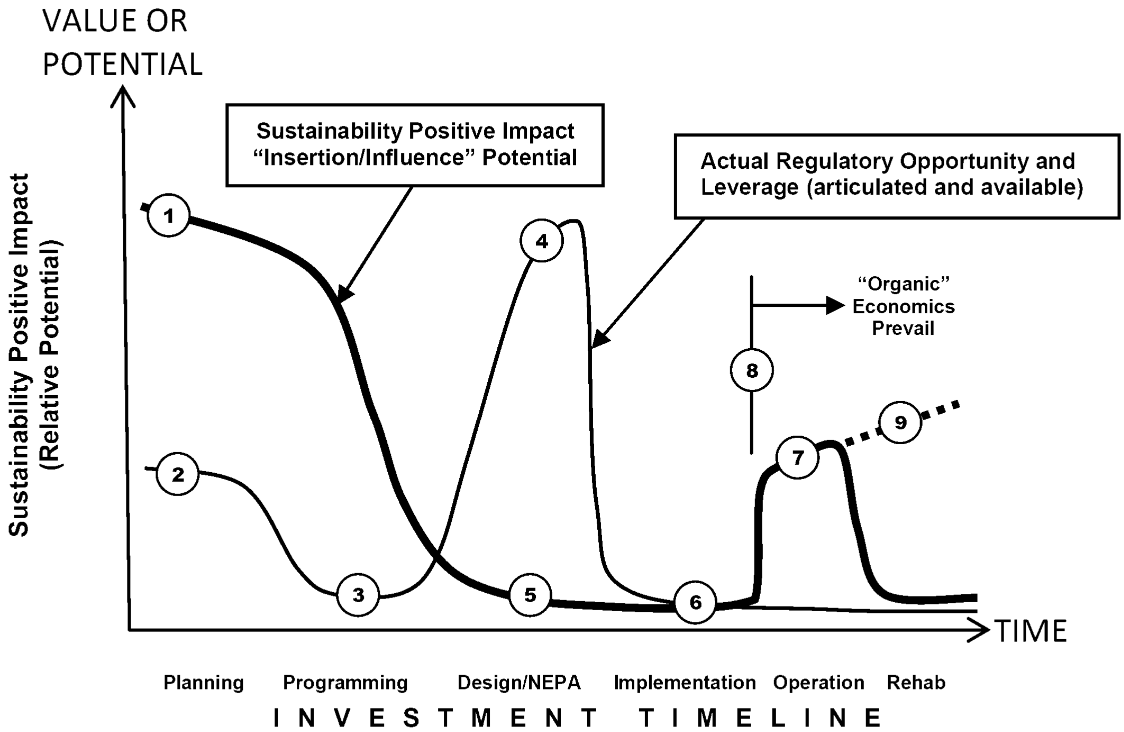


Figure 4 - *General relationship of sustainability potential and opportunity versus investment timeline, hypothetical U.S. transportation example in current practice context (note: numerical references are to explanatory content in paper)*

© ASCE 2014

In Figure 4, the heavier black line shows more the "potential" condition (including limitations of current practice), while the lighter line illustrates available regulatory leverage. The following notations, corresponding to the circled numbers in the Figure 4 illustration, provide additional explanation:

1. **The potential for the strongest imprint on total sustainability outcomes is in the planning and programming stage; the potential is there even in current practice but the work is usually incomplete**
2. **Most projects start with a far less than optimal planning footprint or authority regarding total sustainability**
3. **Programming, and assignment of resources, is usually constrained in non-hard project accounting; application of broader resources based on benefit stream is needed at this point to achieve potential in programming for sustainability support**
4. **NEPA offers, in theory, powerful leverage for balanced outcomes in support of total sustainability**
5. **Actual potential for total sustainability support in the NEPA phase is severely limited by current procedural nature and challenges**
6. **Potential and corresponding leverage, despite new generation specifications and practices, are relatively low in the construction or implementation phase**
7. **Operation has great potential for sustainability accommodation**
8. **Once a project is operational, basic economics of efficiency and outcome are actually easier to tap and can help drive total sustainability efforts**
9. **As projects enter major rehab or replacement phases, the opportunity for sustainability insertion is high but often lost in shuffle of 3R programming**

In a more favorable framework, the heavier black line at Location 5 would have a significant uptick, reflecting the leverage opportunity (Location 4) available under NEPA at the same point in the project timeline, and helping to backfill and reduce sustainability gaps either missed in project planning, or otherwise not effectively articulated, translated to project scale, or carried forward to the project level.

© ASCE 2014

CONCLUSIONS AND RECOMMENDATIONS FOR THE FUTURE

Despite its noble birthright, NEPA has essentially evolved to permit function. In this mode, NEPA decisions can run contrary to sustainability goals and needs. Many of the most meaningful decisions that affect the opportunity for *true* sustainability at the project level are made, and direction and limitations firmly established, well before the NEPA tool is fully assigned in analysis of a project or action, thus posing significant barriers to subsequent examinations of opportunity. As an unintended result, the powerful sustainability mandate established in Sections 101 and 102 of NEPA is assigned a passive "look back" role that is more defensive than creative at the project level.

In the world of transportation, the vast majority of projects and actions fall below the threshold of detailed, direct, stand-alone scrutiny and reporting for sustainability. The scoping requirement and function of NEPA, for various reasons in current application and practice, typically fails to fill the gap. Planning and macroscale policy mandates at the regional, state or federal level can be important and effective compliments on the sustainability front, but they 1) often are housed and applied in program-level considerations and 2) tend to blur, blend and obscure specific opportunities and measures at the project level[9].

Even the powerful public involvement aspect of NEPA has grown to be a tool and dialogue largely focused on specific impact avoidance, "NIMBY" concerns, and local issues, while the far-reaching expectations of NEPA underscoring sustainability and concepts like net benefit, difficult to covey and technically unwieldy, are hard-pressed to find equitable attention in the public exchange save for an always now common "project greening" display board, web page or color handout piece. As noted by many others[10], "greening" is not equivalent to "sustainable". The challenges to a healthy public conversation under NEPA about true sustainability is not made easier by the continuing trend and insistence in public involvement practice that emphasizes 140-character exchanges and the like, and, therefore, unintended avoidance of some complex but important issues.

Though some states and programs have made (and are making) inroads to a more completely balanced and productive application of NEPA in support of total sustainability, the bulk of the work, and opportunity, is ahead of us.

---

[9] Policy level support of sustainably must necessary make assumptions and establish goals at larger scale in support of a general direction. However, these are not necessarily, in practice, translated or accounted for at the project level in *true* sustainability metrics (i.e. triple bottom line), and as a result may misrepresent or miss project level opportunities, or may even unknowingly foster an undesirable or even significantly adverse imbalance in economic, environmental and social components of true sustainability at the project level, inconsistent with the requirements of NEPA.

[10] Most recently, in NCHRP Report 750 (TRB, 2014).

© ASCE 2014

So, what can be done to better the practice and make NEPA a more accommodating partner for sustainability efforts? A starting short list might look like this:

1. **Planning hand off** – A stronger role for planning to equip NEPA is always good, but the hand off needs to be clear, well-articulated, complete, scoped, and tracked in follow-up.
2. **NEPA accounting** – The "balance" mandate of NEPA, and Section 101/102 intent, needs to be specially accounted for in analysis, documentation and decision making, whether a EA or EIS or CE level project.
3. **Life cycle and operations** – Life cycle costs and impacts need to be more effectively accounted for and addressed, and translated to NEPA decisions and project refinements in design/NEPA phase for total sustainability outcomes.
4. **Rethink sovereignty** – The NEPA process needs to rethink unilateral sovereignty of special concern resources as a given, and consider more complete relationships that can provide better net benefit and sustainable outcomes.
5. **Enhance economic translation and understanding of variables** – More complete economic illustrations, including valuations of resources, is a necessary step in "next-level" sustainability.
6. **Be informed and flexible on programming** – Lack of attention to sustainability needs can be catastrophic to subsequent intents and efforts; programming needs to consider even those "external" components to capture benefit stream and also assign costs.
7. **Step back from rote scripting** – Some elements of NEPA process streamlining intentions do not well accommodate broadly-based NEPA compliance efforts for balanced outcomes and long term net benefit from sustainability insertions.
8. **Treat NEPA as design** – NEPA really needs to be recast and moved away from its "permit" characterization, and treated as a project design element.

* * *

© ASCE 2014

REFERENCES

Barberio, G., Barolsky, R., Culp, M., and Ritter, R. (2008). "PEL – a path to streamlining and stewardship." FHWA *Public Roads,* Vol. 71, No. 5.

Transcend Consulting Group (2009). *Cincinnati I-75 Context and Criteria* workshop proceedings, City of Cincinnati Transportation and Infrastructure Subcommittee (unpublished).

Transportation Research Board (2010). Environmental Analysis in Transportation Committee ADC10 Annual Meeting proceedings, Washington, D.C. (unpublished).

Transportation Research Board (2011). NCHRP Report 708: *A Guidebook for Sustainability Performance Measurement for Transportation Agencies*. Washington, D.C.

Transportation Research Board (2014). NCHRP Report 750 Volume 4: *Sustainability as an Organizing Principle for Transportation Agencies*. Washington D.C.

* * *

© ASCE 2014

MEANS AND METHODS FOR MAKING THE BUSINESS CASE FOR INFRASTRUCTURE PROJECTS IN SUPPORT OF A SUSTAINABLE SOCIETY

Gary McVoy, PhD (202-215-3794, mcvoygr@pbworld.com), Vice President-Transportation, Parsons Brinckerhoff, 1401 K Street NW, Washington, DC, 20005, USA

Philip Schaffner (651-366-3743, philip.schaffner@state.mn.us) Policy Planning Director, Office of Transportation System Management, Minnesota Department of Transportation, 395 John Ireland Blvd, St. Paul, Minnesota, 55155, USA

ABSTRACT

From a public perspective, infrastructure investments are made to serve societal needs and thus the true measure of efficacy becomes their net effect on the Triple Bottom Line (TBL) of economy, environment and society. The perspective lent by the recently published NCHRP Report 750 Volume 4*: Strategic Issues Facing Transportation, Volume 4: Sustainability as an Organizing Principle for Transportation Agencies* "Maturity Model" provides a useful platform for assessing sustainability rating tools in this light. This paper reviews existing and emerging sustainability analysis methods using this construct and demonstrates how a unifying approach using dollar equivalents can be of particular utility in making a business case for societal investment.

PREMISE

If we are to assess the value of a public investment, a framework for assessment is needed. In this paper, it is assumed that the purpose and hence the measure for successful infrastructure investment is the degree to which it supports a more sustainable society as reflected in its net contribution to the triple bottom line.

A Framework for Assessment

The "Maturity Model" outlined in the 2014 "Sustainable Transportation Systems and Sustainability as an Organizing Principle for Transportation Agencies, NCHRP Report 750 Volume 4" provides a useful construct for "*Past, present, and future transportation policy systems.*" Figure 1 outlines a "TBL Mat*urity Assessment Tool'* intended to help state departments of transportation (DOTs) orient themselves as to where they are and where they may want to go in using sustainability as an organizing principle. This convention places compliance with NEPA and other laws and regulations at level one in the continuum of sustainability thinking and analysis. It provides a useful framework for evaluating a range of sustainability assessment tools as they might be applied within a DOT context.

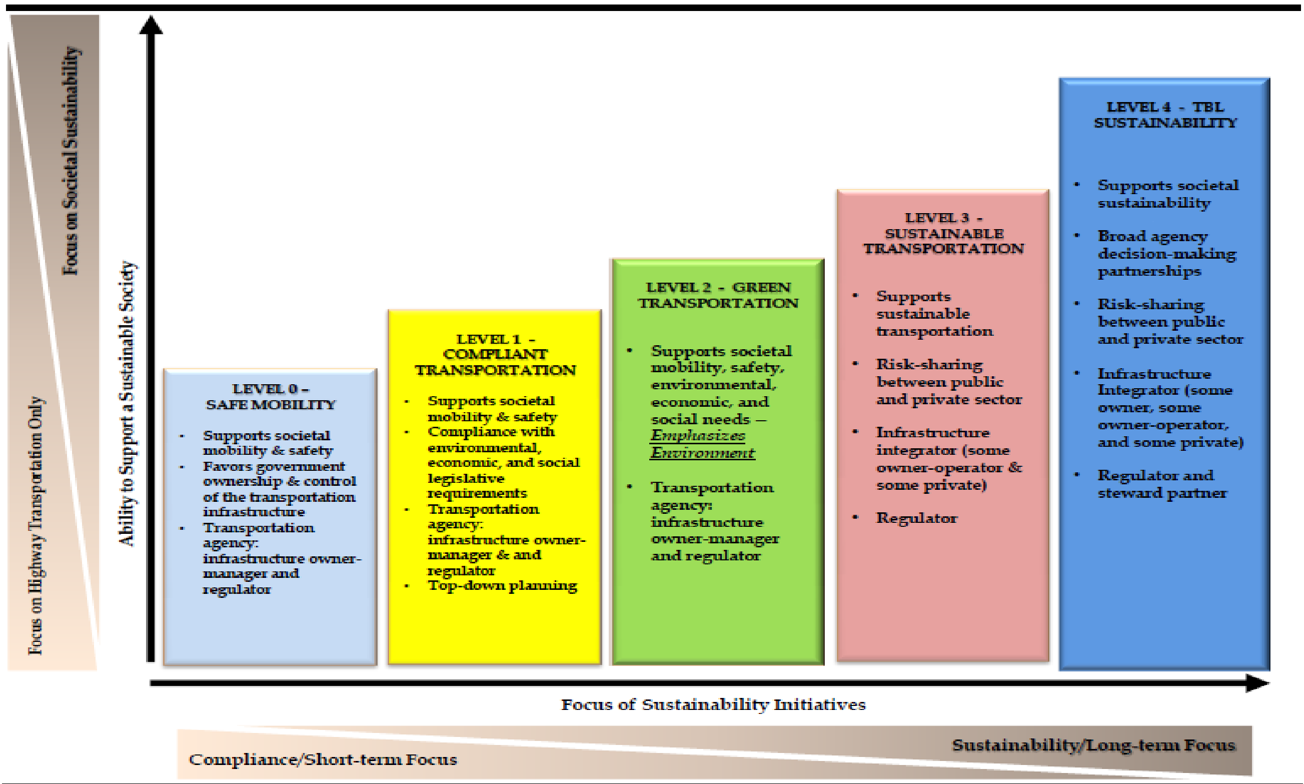


Figure 1 - *Past, present, and future transportation policy systems,*

First do no harm – NEPA

As commonly practiced, NEPA is rightly focused on environmental impact avoidance, minimization and mitigation and tends to document impacts and their mitigation rather than fully vetting the net benefits of an action as they may accrue to society. Accordingly, this "do no harm" focus in NEPA assessments, deliberations, and decisions, tends to overlook the policy vision articulated in Section 101 **(a)** of the statute i.e.,

"*The Congress, ... to* ***foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans.*** *"*

© ASCE 2014

Conventional benefit/cost analysis

Traditional benefit/cost analysis (BCA) has proven to be an effective tool for arriving at clear, transparent, analytically based decisions for the optimization of public investment using monetary terms as adjusted for the time value of money. As such, these analyses can be used to "make a business case" for investment. However, environmental and social effects as addressed in environmental assessments are usually not monetized, and are typically not included in BCA analyses. This leaves gaps in the assessment of the investment's net contribution to a more sustainable society as defined by the Triple Bottom Line. By not expressing the social and environmental effects in "dollar equivalents," traditional BCA fails to fully address conflicting interests and can setup irresolvable tradeoffs (see Figure 2). Traditional BCA provides information appropriate for the level 1-2 in the Maturity Model Perspective.

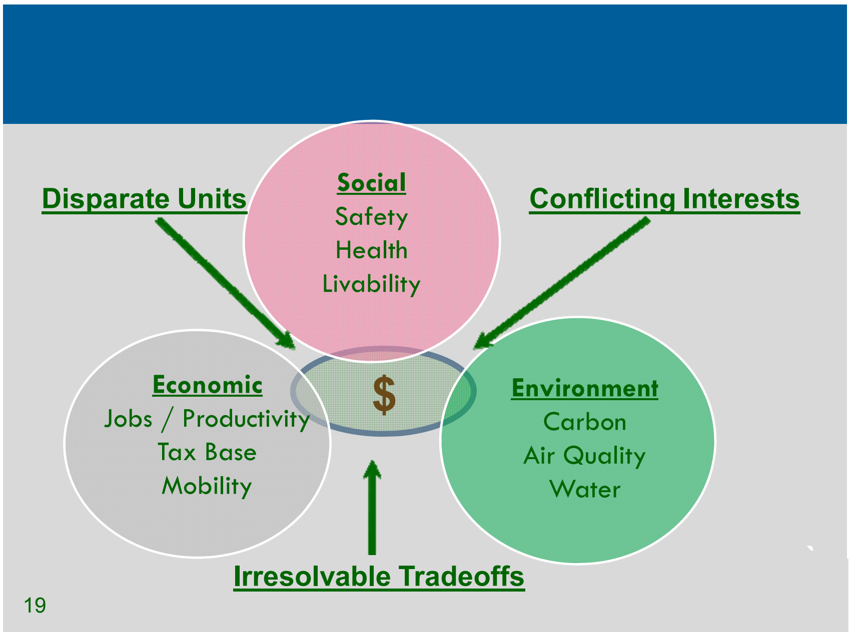


Figure 2: Dollar equivalents as a common metric

Extended and hybrid benefit/cost analysis

An extension of BCA that includes more of the Triple Bottom Line in a transparent and analytical fashion using "dollar equivalents" is the USDOT TIGER Program. The strong advantage here is that many of the factors under consideration as well as the investment parameters themselves are commonly expressed in dollars. Further, since people use dollars in their daily lives, the "value" of a dollar is something familiar and tangible. Table 1 depicts the parameters addressed by the TIGER Program as reported in the Federal Register.

© ASCE 2014

Table 1: U.S. DOT TIGER Considerations

Long-Term Outcome	Type of Societal Benefits
Livability	Land Use Changes that reduce VMT Accessibility Property Value Increases
Economic Competitiveness	Travel Time Savings Operating Cost Savings
Safety	Prevented Accidents (property damage), Injuries and Fatalities
State of Good Repair	Long Term Replacement Maintenance & Repair Savings Reduced VMT from not closing bridges
Environmental Sustainability	Environmental benefits from reduced emissions

Source: Federal Register Volume 77, No. 20, January 2012

However, the TIGER Program in practice tends to overlook a number of important factors with ambiguities in their unit value. In effect, they default to a value of zero. Figure 3 list factors typically affected by transportation investments and flags those typically addressed in project valuations.

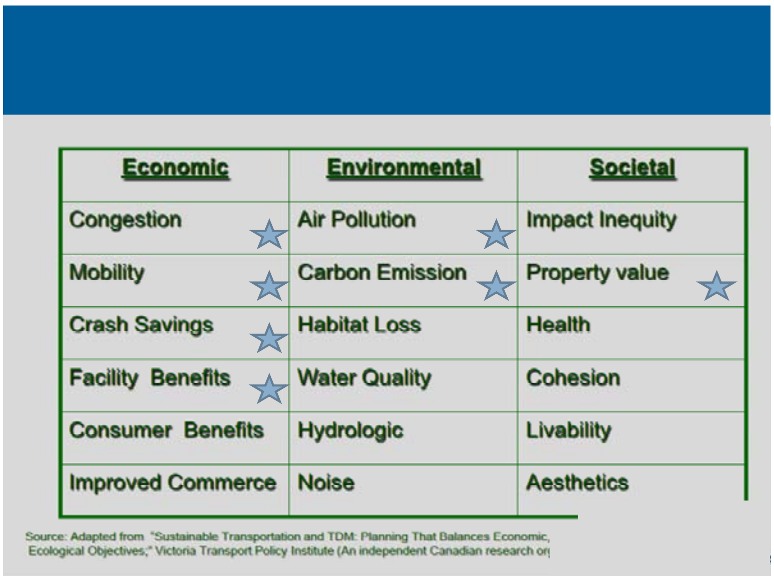


Figure 3: Transportation Factors and the USDOT TIGER Program

However, a catalog of well-established methods for assessing values in the absence of direct market experience does exist (Figure 4) and these can be employed to broaden the base of factors used to assess investment contribution across the Triple Bottom Line. Note also the utility of "sensitivity analyses" for exploring the relative importance of the various factors and indicating the degree of research required to arrive at a degree of precision and accuracy in unit factors sufficient for decision purposes at Level 3 of the Maturity Model.

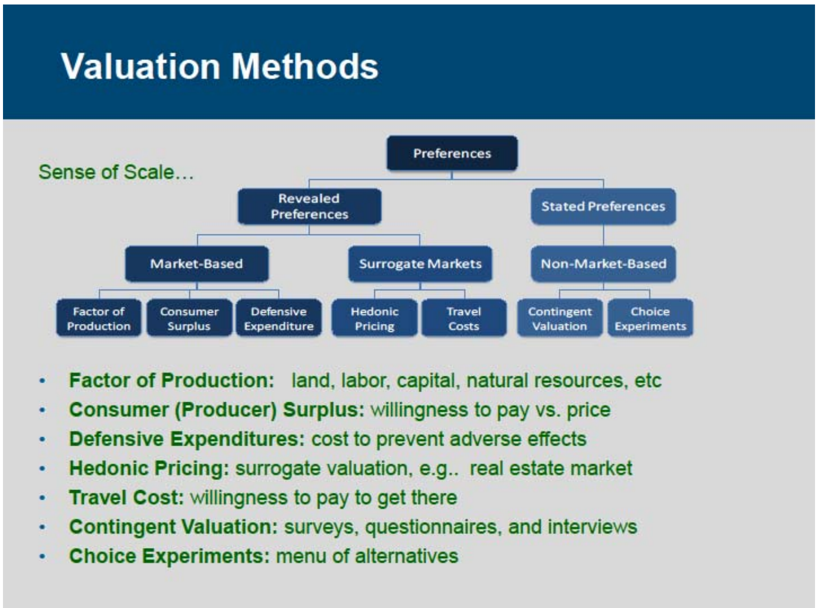


Figure 4: Value Assessment Techniques

Minnesota DOT Sustainability Evaluation Example

As applied recently in Minnesota and discussed in McVoy et al, the Minnesota Department of Transportation's (MnDOT) Corridor Investment Management Strategy (CIMS) provided $30 million under a competitive solicitation to fund projects that improve quality of life, environmental health, and economic competitiveness to advance the state's Minnesota GO vision for transportation. Through CIMS, MnDOT placed a strong emphasis on building and maintaining a sustainable transportation system through the use of solutions that ensure high return-on-investment and complement the unique social, natural and economic features of Minnesota as listed in Table 2. The CIMS solicitation intentionally cast a wide net for projects that address issues for which MnDOT has traditionally no system performance targets and were therefore unlikely to address through the normal programming process.

In evaluating projects, MnDOT used the tool PRISM™ to conduct an extended BCA analyses with the following criteria (as reported on the CIMS website).

Benefit-Cost Calculation (60% of project score)

Using an analysis tool created by the consulting firm Parsons Brinkerhoff called PRISM™ a benefit-cost ratio will be calculated for each project proposal that considers the following social, economic and environmental factors:

Social	Economic	Environmental
• Safety • Bicycle/Pedestrian health effects • Noise	• Travel Time • Travel Time Reliability • Vehicle Operation Costs • Life Cycle Costs • Loss of Agricultural Land • Induced Economic Activity	• Emissions (CO_2 + criteria pollutants) • Wetland Effects • Runoff

Table 2: CIMS Factors used in the PRISM Model

Source: http://www.dot.state.mn.us/cims/pdf/CIMS%20Solicitation%20Criteria%20Summary.pdf

These factors are evaluated using data compiled from program applicants as listed in Table 3.

Data Requested	Safety	Bicycle/Pedestrian Health	Noise	Travel Time	Travel Time Reliability	Vehicle Operation Costs	Lifecycle Costs	Agricultural Land	Induced Economic Activity	Emissions	Wetland Effects	Runoff
Vehicle Miles Traveled	✓		✓			✓				✓		
Vehicle Hours Traveled				✓	✓							
Average Bus Headways				✓								
Average Bus Occupancy				✓								
Bicycle Miles Traveled		✓		✓								
Pedestrian Miles Traveled		✓										
Annual Number or Rate of Crashes	✓											
Average Speeds			✓							✓		
Annual Average Daily Traffic			✓									
Quantity of Wetlands Affected											✓	
Quantity of Agricultural Land Affected								✓				
Site Area Acres												✓
Site Composition by Ground Cover Type												✓
Contribution to Combined Sewer Outflow												✓
Initial Construction Costs							✓		✓			
Operating and Maintenance Costs							✓					
Rehabilitation Costs							✓					
Infrastructure Replacement Costs							✓					
Expected Lifecycle of Major Capital Items							✓					

Other impacts may be included the PRISM B/C calculation provided analysis has already been done to estimate the benefits. Examples: Brownfield site cleanup benefits, energy supply impacts, "green" technology lifecycle cost savings, impact to species habitat, etc.

Table 3: Corridor Investment Management Strategy Pilot Data Needs

Source: http://www.dot.state.mn.us/cims/pdf/CIMS%20Solicitation%20Criteria%20Summary.pdf

© ASCE 2014

In addition to the PRISM™ criteria, other more qualitative factors were evaluated by an interagency selection committee to yield a final list of priority projects to maximize public return on investment. These included the following:

- Local Economic Impacts
  - Creation/retention of non-project construction jobs relative to the size of the project
  - Improves access for designated tourist destinations or schools/universities
- Context Sensitivity
  - Consistency with surrounding land uses
  - Avoids/minimizes impacts to or enhances natural, historical, archeological and cultural resources
- System Considerations
  - Closes or addresses a system gap
  - Adds redundancy to the system necessary to improve system reliability
  - Is consistent with existing plans for the region or corridor (Scenic Byway, MPO/Local Plans, etc.)
- Community Health and Access
  - Improves access to preventative and clinical health care facilities or recreational facilities
  - Avoids/minimizes negative impacts to or positively improves access for low-income or disadvantaged populations
- Multi-modal Impacts
  - Includes Complete Streets treatment
  - Improves transit service, rail service (freight or passenger), access to airport/port/intermodal facilities, or conditions for pedestrians, bicyclists or other trail users

This approach represents one of the first efforts by a DOT to use the dollar equivalent to transparently analyze a wide range of benefits and costs across the triple bottom line. This Triple Bottom Line Valuation builds upon the information typically contained in environmental analyses to bring economic and social factors onto a level playing field in a transparent and defensible manner across a full range of factors. By bringing analytical rigor to the principles of sustainability, the approach has helped focus dialogue and provided an enriched understanding of the potential benefits and impacts of infrastructure projects, plans, policies, and programs beyond that which would be possible using NEPA or conventional multi criteria analysis tools. Further, the approach also lends itself to prioritization of retrofit activities on the same basis as capital improvement projects. This approach would be appropriate for Level 3-4 of the Figure 1 Maturity Model.

© ASCE 2014

Sustainability life cycle costing

An extension of BCA that incorporates environmental, social, and economic concerns and includes the entire Triple Bottom Line in a transparent and analytical fashion using “dollar equivalents” has shown promise as a means to inform and enrich conversations on the relative advantages of alternative investments in an extension of applications such as the USDOT TIGER and the MnDOT CIMS Program analyses.

While the TIGER and CIMS Programs focus on capital projects, Table 4 from *NCHRP 25-25/Task 73 Improved Environmental Performance of Highway Maintenance (McVoy 2012),* has suggested how sustainability life cycle costing might apply to a wide range of maintenance activities with an eye toward “ecological restoration” as a normal part of highway system maintenance. The table shows maintenance activities as they relate to a range of triple bottom line factors.

MAINTENANCE -- TRIPLE BOTTOM LINE TABULATION

Program	Activity	Cycle (yrs)	#	#/ YR TARGET	# STATE FORCES	# CONTRACT	CAPITAL $	STATE CASH $	LIFECYCLE $	MOBILITY $	JOBS $	AIR $	WATER $	HABITAT $	SAFETY $	ACCESS $	LIVABILITY $		BENEFIT / COST
Bridges	Bridge Cleaning								X	x	y								X
	Bridge Painting								X	x	y								X
	Deck Sealing								X	x	y								X
	Deck Treatment								X	x	y								X
	Joints								X	x	y								X
	Bearing Restoration								X	x	y								X
	Punch list From Inspection								X	x	y								X
	Environmental Protection										y	x	x	x					X
	Storm Water Facility										y	x	x	x					X
	Stream Channel										y	x	x	x					X
	Check for Invasive Species										y	x	x	x					X
	Regulatory Cost (Fines)								x		y	x	x	x					X
	Safety									x	y				x	x	x		X
	Public Parking / Access										y				x	x	x		X
	Historic / Cultural Signing										y				x	x	x		X
Pavement																			
Drainage																			
Signals & Lighting																			
Roadside																			
Guiderail																			
Signs																			
SNOW & ICE																			
Facilities																			
$$ TOTAL																			

Table4: Maintenance Activities and the Triple Bottom Line

Table 5 illustrates how such an approach might be extended as a comprehensive analysis and public outreach tool as envisioned at Maturity Model Level 4.

© ASCE 2014

TRB Metric eg									
Economic	**Units**	**# Units**	**$eq/Unit**	**Present $ Value**	**Discount Rate**	**Qualitative Assessment**	**Public Comment**	**Reference Links**	**Other Notes**
Leisure Travel Time Savings	hours								
Worker Travel Time Savings	hours								
Vehicle Operating Costs	$ / mile								
Freight Congestion Reduction	hours								
Transit Accessibility	trips								
Property Value	$/ unit								
Jobs	# / year								
Income	% change								
Additional									
Economic									
Environmental									
Air Toxics	tons								
NAAQS	tons								
Noise	dBA								
Hazardous Waste	tons								
Additional									
Environmental									
Social									
Access to Services	# people								
Access to Employment	# people								
Access to Recreation	# people								
Community Cohesion	# people ?								
Vehicle Safety	# crashes								
Ped / Bike Safety	# crashes								
Additional									
Social									
Total Net Benefits									

Table 5: Range of valuations as could be determined through public input

Figure 5 takes this a step further and illustrates how a range of valuations might be derived from public survey, thus informing the conversation as to the net valuations in question for the affected stakeholders as an aid to improved decision making. And, since such valuations would reflect a range of preferences rather than single values, they are best expressed in terms of probability. These valuation probabilities can in turn can be concatenated with the range of likely impact or benefit units using Monte Carlo techniques (as already done with Impact Infrastructure's Business Case Evaluator [1] as well as in other emerging evaluation tools) to yield a range of net probable benefits by component. Sensitivity analysis of these component values can then be used to determine the "principle drivers" of the analysis, and hence the likely range of effects and the utility of improved estimates across the range of factors.

[1] http://www.sustainableinfrastructure.org/downloads/index.cfm IBID

© ASCE 2014

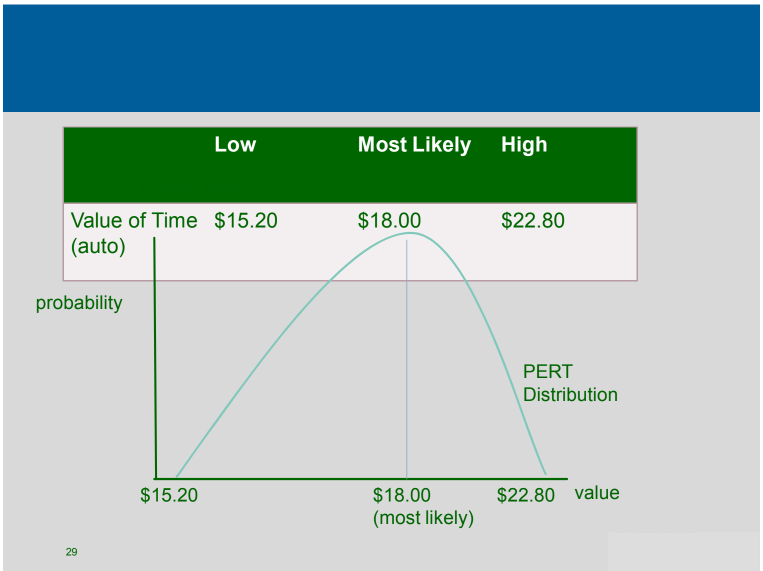


Figure 5: Probability Density Function (PDF) reflecting Public valuation

Further, the process and the results of a public vetting of valuations for sensitivity analysis within a transparent analytical framework could enable public agencies to approach Level 4 of the Maturity model, i.e. effectively communicate with other stakeholders using a transparent analytical framework to advance a more holistic approach in support of a more sustainable society.

Conclusion

Investments in a more sustainable future require consideration of a comprehensive range of inter-related objectives across the entire Triple Bottom Line (TBL) of economy, environment and society. NEPA analyses are very useful in helping to avoid, minimize and mitigate environmental impacts, but if a more comprehensive and businesslike treatment of the full range of factors is needed, than a more comprehensive and businesslike approach is needed. Multi criteria analyses broaden the scope of concerns, but lack an accounting for the full range of benefits and impacts that can be expected to accrue from the subject investment. Benefit cost analyses use dollars to address the efficacy of investment, but tend to leave out important social and environmental factors because they are difficult to precisely monetize. However, lacking some common metric, choices among competing objectives remain subject to vagaries of opinion among stakeholders.

An extension of BCA for the quantification and optimization of infrastructure benefits within a TBL construct that includes a broader range of sustainability factors has been applied in Minnesota and has advanced the sustainability dialogue. While use of sustainability life cycle benefit / cost is still in its infancy, it does show promise as a more complete, transparent and inclusive approach to the development of infrastructure in support of a more sustainable society.

© ASCE 2014

REFERENCES

Booze Allen Hamilton; Sustainable Transportation Systems and Sustainability as an Organizing Principle for Transportation Agencies [1] *NCHRP Report 750: Strategic Issues Facing Transportation, Volume 4: Sustainability as an Organizing Principle for Transportation Agencies,* http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_750v4.pdf

Greenroads Foundation, Greenroads™, https://www.greenroads.org/

Illinois Livable and Sustainable Transportation Rating System and Guide, I-LAST™ Version 1.01 http://www.dot.state.il.us/green/documents/I-LASTGuidebook.pdf

Infrastructure Voluntary Evaluation Sustainability Tool (INVEST), FHWA Version 1.0 https://www.sustainablehighways.org/

Institute for Sustainable Infrastructure, Envision™, http://sustainableinfrastructure.org/

McVoy, Gary. *NCHRP 25-25/Task 73 Improved Environmental Performance of Highway Maintenance*, (2012).

McVoy, Gary and Gunasekera Kumudu, "PRISM tblv: Triple Bottom Line Valuation Tool" in Economic Forecasting Review, Vol. 5 Issue 1, 2011 (http://www.pbworld.com/news/publications.aspx#efr)

Minnesota DOT, Corridor Investment Management Strategy, http://www.dot.state.mn.us/cims/solicitation.html

New York State DOT, GreenLITES, https://www.dot.ny.gov/programs/greenlites?nd=nysdot

North American Sustainable Transportation Council, Sustainable Transportation Analysis & Rating System (STARS), http://www.transportationcouncil.org

© ASCE 2014

MARTA Project Delivery Approach: A Summary of the Program Implementation Plan for MARTA System Expansion Projects

Adelee Marie Le Grand, AICP[1]; Cheryl L. King, AICP[2]; Richard Wolsfeld, AICP PE[3]

[1]AECOM, 1360 Peachtree Street NE #500, Atlanta, GA 30309
[2]Metropolitan Atlanta Rapid Transit Agency, 2424 Piedmont Road NE, Atlanta GA 30324
[3]AECOM, 303 E. Upper Wacker Drive #1400, Chicago, IL 60601

Abstract

In 2013, the Metropolitan Atlanta Rapid Transit Authority (MARTA) undertook a study to identify and evaluate alternative delivery methods to advance high-capacity transit expansion projects in the Interstate 20 (I-20) Corridor, the Clifton Corridor, a major job and activity center with no direct access to existing rail transit and the regional freeway system, and the GA 400 Corridor. The study resulted in the identification of the preferred delivery method and implementation plan for each of these corridor projects. This paper details the consensus reached for the three MARTA projects selected for implementation, the sources of funding for the financial plan, and the preferred project delivery methodLa.

To accomplish this effort, five major tasks were undertaken which define the schedule, financial plan, and implementation method for the I-20 East Heavy Rail Transit (HRT) Corridor, the Clifton Corridor Light Rail Transit (LRT), and the GA 400 HRT projects.

Of the numerous project delivery methods obtained from prior research and case studies, Design-Bid-Finance and Maintain (DBFM) was deemed to be the most appropriate method for both I-20 East HRT and Georgia 400 HRT, and Design-Build-Operate-Finance and Maintain (DBFOM) was deemed to be the most appropriate delivery method for Clifton Corridor LRT.

Introduction

The metropolitan Atlanta region is one of the fastest growing regions in the country, and additional investment is needed to meet Atlanta’s transportation infrastructure needs. These investments include a backlog of critical projects and the mounting need to preserve and maintain key parts of the existing transit system. While MARTA continues to maintain its heavy rail system in a state of good repair, it has not engaged in any significant system expansion projects within the past twelve years. Among the backlog of critical projects are three expansion projects, which are the focus of this paper. These projects are the I-20 East Heavy Rail Transit (HRT), the Clifton Corridor Light Rail Transit (LRT), and the GA 400 Corridor (HRT). All of

© ASCE 2014

these projects are all located within Fulton and DeKalb Counties in Metropolitan Atlanta, Georgia, and have been recognized as important progress in the Atlanta region's goals for reducing dependence on single-occupancy vehicles, improving air quality, improving transit access for minority and low-income populations, and connecting the growing metro area population with regional job and activity centers.

Facing the need to maintain the existing, aging system at a State of Good Repair, the funds for the expansion projects will be challenging to obtain. Increasing budgetary pressures on MARTA may limit its ability to invest in future projects and constraints on federal spending may limit federal transportation funds in the years to come. The convergence of these issues suggests a need to identify new ways by which MARTA finances, delivers, and maintains its system. Consequently, MARTA recognized this need and undertook a thorough investigation of viable project delivery options. This paper discusses key findings from MARTA's alternative project delivery analyses, and they are as follows:

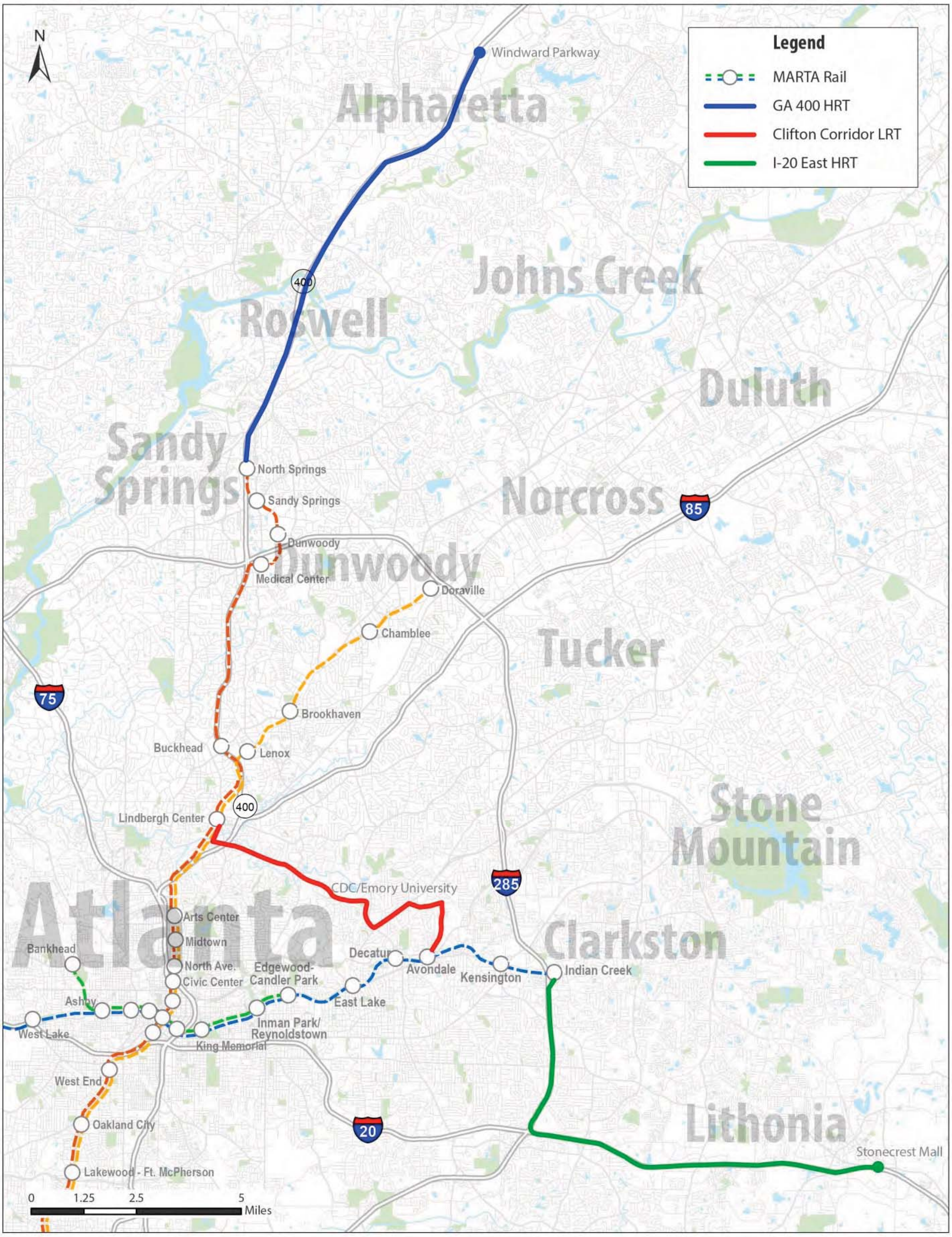
- A summary of MARTA's peer review and lessons learned
- An evaluation of alternative project delivery methods
- Recommended project delivery method and implementation schedules for each project
- A financial feasibility and discussion of funding sources

Location of Projects

Figure 1 provides the location of MARTA's expansion projects, on a regional level and within the realm of MARTA's heavy rail system.

© ASCE 2014

Figure 1 – Location of Corridors



© ASCE 2014

Lessons Learned from Peer Agencies

Transit providers in the U.S. face similar challenges as MARTA; therefore it was beneficial to get an outlook on how MARTA's peers have addressed some of these challenges. Peer transit agencies were selected based on their previous successes with utilizing alternative project delivery methods; their approach for infusing dollars for service expansion; their comparable institutional structure; as well as other criterion. MARTA's peer review provided context for subsequent analysis and discussion of alternative project delivery methods.

The peers selected were the Los Angeles County Metropolitan Transportation Agency (LACMTA), Denver Regional Transportation District (RTD), and Dallas Area Rapid Transit (DART) transit agencies; discussions with each peer also involved actual site visits. Lessons ranged from the use of external consultants, to determining a sustainable revenue source, to increasing a transit agency's chances of obtaining Federal funding for capital expansion projects (Recent North American Alternative Project Delivery Projects). Some of the lessons learned during the peer review are as follows:

- **Alternative Project Delivery** - Alternative Project delivery options have been successfully tested in numerous cases and they should be evaluated for all major transit investments.
- **Organization** – the Engineering Department of a transit agency can successfully have responsibility for both State of Good Repair (SOGR) and New Starts projects.
- **Revenue Source** – Alternative Delivery does not generate revenue; it has the potential to lower costs. Therefore, MARTA needs a sustainable funding source to pay for new transit investments.
- **Relationship with Federal Transit Administration (FTA)** – using Alternative Project Delivery can improve the chances of obtaining federal New Starts funds.
- **Use of Consultants** – for an agency doing their first Alternative Delivery project, use of outside consultants was highly recommended by the three agencies.

Feedback from peer transit agencies was also used to develop a concise set of project goals, which helped establish criteria for selecting the appropriate project delivery method and provided a framework for measuring project success over time. The project goals were:

- **Schedule** – Minimize project delivery time, complete the project on schedule, and accelerate the start of project revenue.
- **Cost** – Minimize the project cost, maximize the project budget, and complete the project on budget.
- **Quality** – Meet or exceed the project requirements and select the best team.
- **Sustainability –** Minimize impact on the environment and achieve LEED certification

© ASCE 2014

Implementation Method for Each Defined Project

After receiving feedback from MARTA's peers, the next step was evaluating multiple alternative project delivery methods. A total of five methods were evaluated in terms of their overall structure, requirements, and funding implications. Evaluating the various delivery methods was integral in setting the stage for the actual choosing of the most appropriate delivery method for each expansion project.

The full range of Public Private Partnership (P3) options available and ones previously applied to projects of similar scale was considered. The most appropriate potential project delivery strategies from the P3 options are listed below:

- Traditional Design-Bid-Build (DBB) Contract—This generally involves a public agency contracting with separate entities for each stage of project development, including planning, design, construction, and operations.
- Design Build (DB)—This model transfers a majority of the design and construction risk to the private sector by selecting one private entity to perform both functions, which can be a single firm or a joint venture company. Instead of relying exclusively on the lowest bid, design-build elections are usually based on the "best value" bid using preliminary design documents.
- Design Build Operate and Maintain (DBOM)—Similar to the design-build approach, but also includes a short to medium term operational and maintenance responsibility for the private partner. This structure promotes additional innovations during the construction and design process, as the private partner is motivated to produce a high quality asset that performs well over the life of the contract and has manageable maintenance costs.
- Design Build Finance and Maintain (DBFM)—this model combines the innovations of design-build with some amount of private sector capital (debt or equity), as well as a short to medium term capital maintenance responsibility for the private partner. Often, this model will combine private sector funds with existing public sources, allowing the private capital to fill any gaps in funding. However, unlike DBOM, the public sector retains the responsibility for operations.
- Design Build Finance Operate and Maintain (DBFOM)—this model is similar to the DBOM approach, with the private partner also responsible for financing. The use of private financing can allow the project to be built faster. The public sector is still responsible for the revenue stream to support the private financing, which can come from public sources, such as annual appropriations or dedicated tax revenues. These revenues are then paid in annual installments (known as "availability payments") to the private partner, on the condition that the transportation facility is "available" and meets agreed-upon performance specifications. The private partner then uses these payments to pay operating and maintenance costs, cover debt service, and provide returns to equity investors (Summary of Initial Findings).

© ASCE 2014

These alternative delivery methods were analyzed for each of the expansion projects. A Go/No Go assessment was performed for each project under evaluation, and certain "fatal flaws" were determined that could render one or more delivery methods inappropriate for certain projects. For example, for projects that involved an end-of-line extension of existing MARTA services such as the I-20 East HRT and GA 400 HRT projects, the transfer of Operations to a private entity—whereby a single transit line would be divided among two operators, with different maintenance yards, etc.—was considered impractical.

Through this analysis, Design-Bid-Finance and Maintain (DBFM) was deemed the most appropriate method for both I-20 East HRT and Georgia 400 HRT, and Design-Build- Finance-Operate and Maintain (DBFOM) was deemed the most appropriate delivery method for Clifton Corridor LRT. The additional private operations component is appropriate for the Clifton Corridor project because it would be a separate transit line and technology, as opposed to the other two projects, which are extensions of existing MARTA heavy rail lines that should continue to be operated by MARTA.

After selecting the appropriate delivery method for each project, the next step was to develop an implementation schedule.

Project Implementation Schedules

The alternative project delivery methods, DBFM and DBFOM, impact scheduling and phasing, which also affect project costs. Based on the chosen delivery method for each project, an accompanying schedule was developed. Corresponding to the implementation schedule, projected costs were calculated to provide a comparison between traditional and alternative delivery methods, which helped convey time and cost savings. A description of the methodology is provided in the following sections.

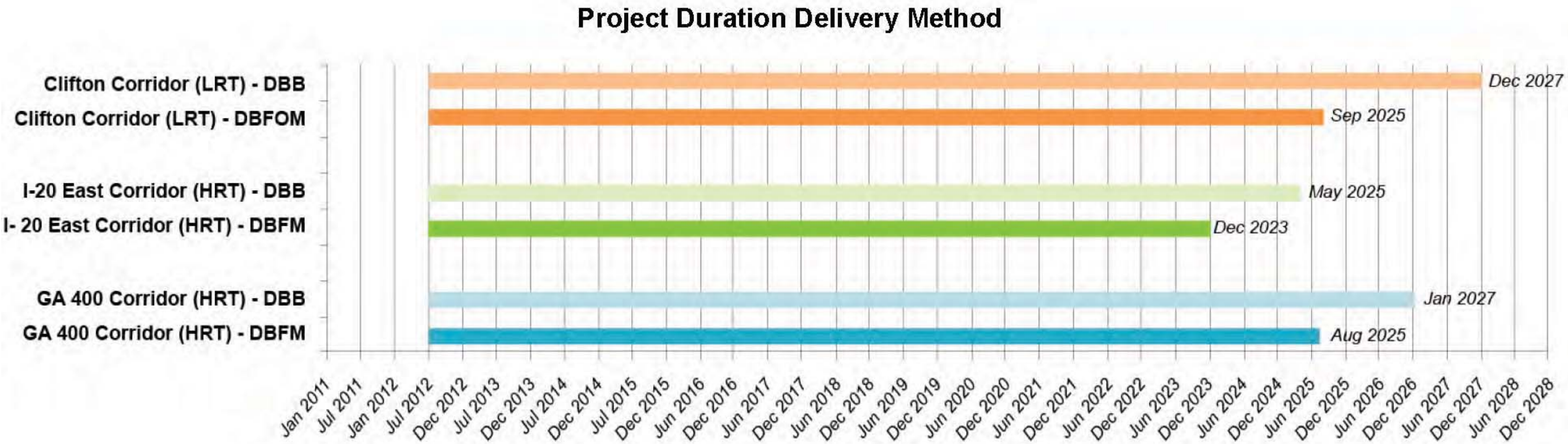
For each project, a preliminary baseline schedule was initially developed based on a Design-Bid-Build (DBB) delivery method (typically referred to as the "traditional" delivery method). Once a preliminary determination of alternative delivery methods was developed for each project, new schedules were created to compare these delivery methods.

Project costs for the traditional DBB delivery method were calculated for each project using the Federal Transit Administration's (FTA) Standard Cost Categories (SCC) for Capital Projects workbook. This takes into account categories such as guideway and track elements, stations, support facilities, site work, control systems, right-of-way purchasing, vehicles, and professional services. It also provides a project schedule, which was utilized for time savings estimates. To calculate cost savings due to alternative project delivery, resource loaded cost schedules were created for each expansion project. These schedules took into account the annual time savings that resulted from alternative delivery, and applied it to the estimated costs for major schedule items, such as project development, procurement, engineering, and construction/testing. This resulted in annualized cost comparisons for each project of DBB versus the alternative delivery methods mentioned previously. The preferred delivery methods were chosen based on these calculations.

© ASCE 2014

Figure 2 provides a summary of an alternative project delivery schedule for each expansion project. It also shows the time savings that result from using the preferred project delivery approach for each corridor project. The Clifton Corridor LRT project would see an estimated time savings of 2.2 years from the DBFOM method instead of the traditional DBB method--the greatest time savings of all projects due to alternative delivery methods. The I-20 East Corridor HRT project would see an estimated project duration savings of 1.4 years from the DBFM method. The GA 400 Corridor HRT project would see an estimated time savings of 1.4 years also as a result of utilizing the DBFM project delivery method (Draft 10 Year Schedule Memo). If all three expansion projects pursued the traditional DBB method, the capital costs would be $1.83 billion, $1.38 billion, and $2.27 billion for I-20 HRT, Clifton LRT, and GA 400 HRT, respectively. Alternative project delivery methods would result in capital costs of $1.65 billion, $1.19 billion, and $2.08 billion. These represent savings of 10%, 14%, and 8%, respectively.

Time savings for all MARTA expansion projects are mostly due to the ability of alternative delivery methods to condense all time-dependent construction activities through the use of a uniform design and construction approach. Much of the cost savings resulting from alternative delivery methods are due to compressed time-dependent tasks and the bundling of the design and construction contracts to one private entity to perform both functions. Such design-build contracts are usually based on the “best value” bid, where the entities are encouraged to innovate in ways that can save time and costs.



Project	Selected Alternative Delivery Method	Estimated Time Savings	Estimated Cost Savings	System Opening based on Delivery Method	
				Traditional	Alternative
Clifton Corridor (LRT)	DBFOM	2.2 years	14%	Dec 2027	Sept 2025
I-20 East Corridor (HRT)	DBFM	1.4 years	10%	May 2025	Dec 2023
GA 400 Corridor (HRT)	DBFM	1.4 years	8%	Jan 2027	Aug 2025

Figure 2 – Alternative Project Delivery Schedule

© ASCE 2014

Funding Needs for Each Project

At this juncture of the analysis, MARTA so far had received insightful feedback from its peers; evaluated project delivery methods; and developed project profiles for each project consisting of implementation schedules and associated cost impacts. Yet, this acquired knowledge can be treated as futile without a clear understanding along with a game plan for acquiring the needed funding for the expansion projects. Consequently, MARTA's next task was developing a financial outlook (e.g. preliminary financial plan) of its funding sources and needs.

To develop the preliminary financial plan, each project's projected capital costs, operating revenues, potential funding sources, and various financing structures were examined to determine the financial feasibility of implementing the three corridor expansion projects. Conventional financing structures, innovative financing approaches, and public/private sector project delivery were considered for project implementation.

The analysis recognized uncertainties associated with inflation, interest rates, project costs, operating and non-operating revenues, and level and timing of private equity in developing a robust and implementable plan. **Table 1** shows the summary of funding needs for the projects.

The funding needs assume that 50% of the capital costs would be paid for by the Federal government, through a grant program such as FTA New Starts, and that the remaining 50% of capital costs would be paid for by a local match. Because each project requires a large capital investment, it was assumed that MARTA would apply for a 35-year Transportation Infrastructure Finance and Innovation Act (TIFIA) loan, which is a Federal credit program for transportation projects under which the U.S. Department of Transportation may provide direct loans, loan guarantees, or standby lines of credit (fta.dot.gov). It was assumed that the total local annual cost for each project would be required for the full term of the loan, which is 35 years.

TIFIA assistance can help accelerate nationally and regionally significant transportation investments that otherwise might be delayed or deferred because of size, complexity, or uncertainty over the timing of revenues. However, certain criteria must be met in order to qualify for TIFIA assistance. Criterion includes:

- Minimum project cost: $50 million;
- Federal funding cannot exceed 33% of eligible costs or the amount of senior debt if the TIFIA loan does not have an investment grade rating;
- Senior debt obligations must receive an investment grade rating; and
- The project must have a dedicated revenue source to pledge as repayment on the TIFIA loan.

Once the funding needs were established, the analysis determined the extent to which projected operating and non-operating revenues would cover capital, operations, and maintenance costs of the program. It was determined that with a TIFIA loan at current interest rates (2.99% in February 2013), the total local annual cost for Clifton LRT, I-20 HRT, and GA 400 HRT would be $49 million, $56 million, and $68 million, respectively.

© ASCE 2014

Table 1 - Summary of Funding Needs for All Projects

($2012 Millions)

PROJECT	CAPITAL COST	ANNUAL LOCAL CAPITAL COST	ANNUAL O&M DEFICIT	TOTAL LOCAL ANNUAL COST	CAPITAL MAINTENANCE
CLIFTON LRT	1,190	38	11	49	3 -5% of capital cost
I – 20 HRT	1,650	43	13	56	3-5% of capital cost
GA 400 HRT	2,080	54	14	68	3-5% of capital cost
TOTAL	4,920	135	38	173	3-5% of capital cost

All costs in $2012 Millions. Cost estimate obtained from project documents.
Assumes 50% of capital cost funded by FTA
Total does not include Capital Maintenance

Local Funding Sources

After MARTA established a financial outlook on the traditional funding sources (e.g. Federal match, TIFIA), the financial gap for these projects became evident. Focus was then shifted to determining the availability and willingness of local funding. At this juncture, it was a prime opportunity to engage local stakeholders; whereas they would be presented the analysis conducted thus far and most importantly can attest firsthand to the funding shortfall(s). Typically as in any other location in the U.S., whenever local funding options are on the table, there are multiple variables to address (i.e. assessing available funding, gauging local governments’ willingness to co-sponsor projects). The following section provides highlights from MARTA’s assessment of available local funding and its stakeholder outreach.

© ASCE 2014

MARTA is currently the largest mass transit system in the U.S. that does not receive any dedicated, annual state operating funding (Comprehensive Annual Financial Report). The majority of MARTA's funding comes from a 1% sales tax in Fulton and DeKalb counties, but many other county-level funding mechanisms exist, such as property taxes, hotel/motel taxes, and others. Regional sources have been difficult to implement in the past—the metro Atlanta region voted against a referendum to allow a 1% sales tax increase in 2012 that would have funded a variety of transportation projects, but certain parts of Fulton and DeKalb counties voted in favor of this tax.

A funding framework and potential local funding sources were developed, in order to meet the TIFIA criteria that projects must have dedicated revenue sources to pledge as repayment (Definition and Screening of Potential Funding Sources, MARTA). The potential local funding sources are displayed in **Figure 3**.

© ASCE 2014

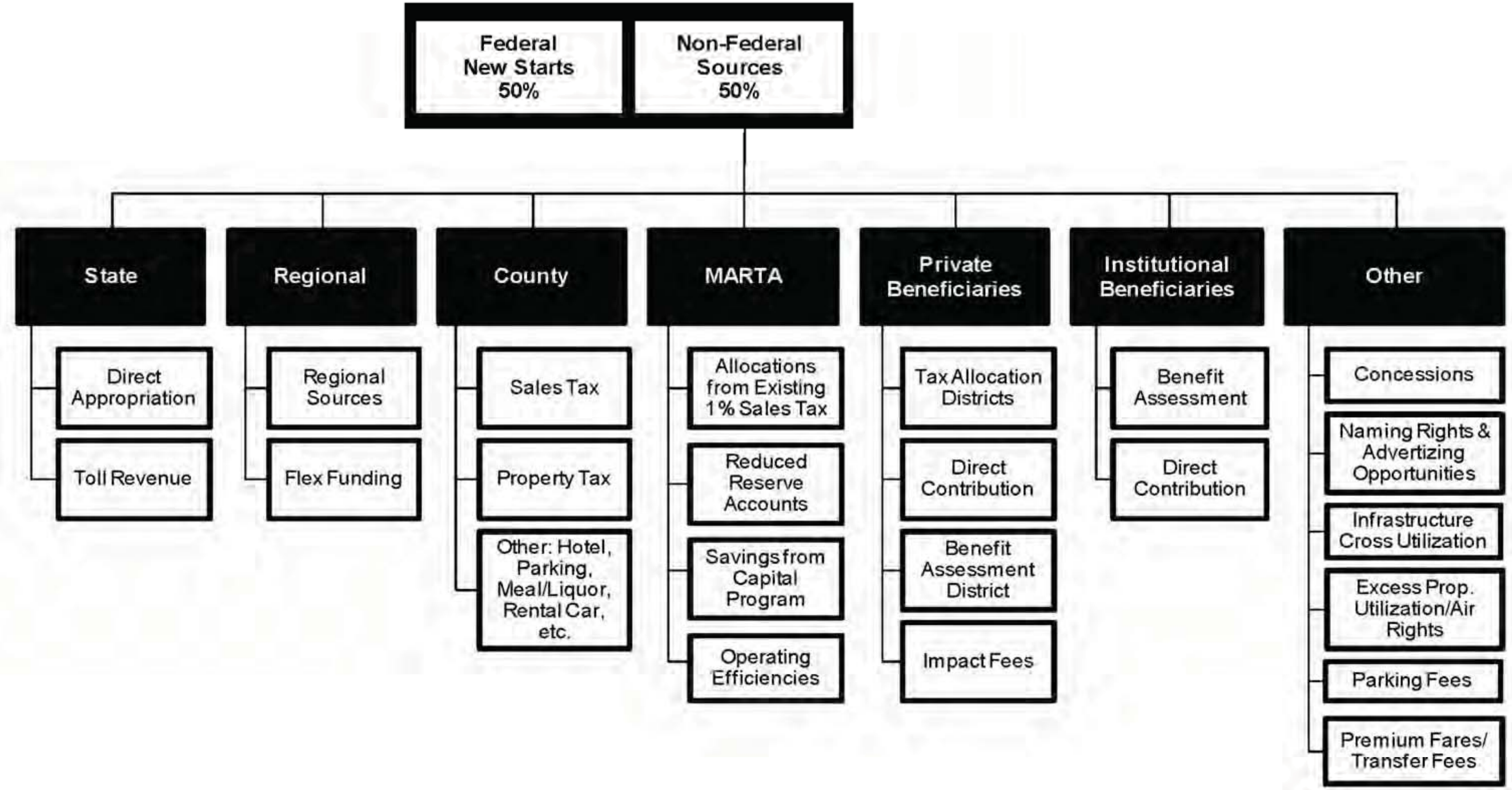


Figure 3 – Potential Funding Sources for MARTA Development Projects

© ASCE 2014

After the full range of potential funding sources was identified (Figure 3), the sources were subjected to evaluation criteria to narrow the choices down to a total of eight. The evaluation was based on four criteria:

- Yield – The amount and growth of the revenue stream over time;
- Equity – Impact on different population segments
- Legality – Requirements for any new legislation and/or regulations to implement the source; and
- Political Acceptability – Degree of support by governments, key stakeholders, and the public.

After funding sources were screened out via the evaluation criterion, the following were chosen for further consideration:

- State direct appropriation;
- County sales tax for Fulton, DeKalb, and City of Atlanta;
- County property tax; tax allocation districts;
- Community improvement districts;
- Direct contributions; and
- Naming rights and advertising opportunities (Definition and Screening of Potential Funding Sources).

The annual yield for each of the capital funding sources listed above depends on a variety of scenarios, which can be different for each MARTA expansion project. For example, higher levels of county sales and property taxes could provide the majority of capital funding necessary for a project, but a larger tax increase may be less politically feasible and unacceptable to the public, as opposed to an incremental increase.

Based on the potential funding sources considered to be finalists, a series of funding scenarios was created and presented at various stakeholder meetings. The stakeholders for each project were then given the opportunity to propose their own funding scenarios to obtain the necessary annual capital to pay back the Federal TIFIA loan. Stakeholder meetings were held for each expansion project. As a result of stakeholder outreach, MARTA was able to identify alternative project delivery methods that were industry tested as well as being supported by potential users of the expanded transit service.

Summary

While the upfront costs of the three MARTA expansion projects initially seem high, alternative project delivery methods are necessary to make the capital costs of the projects more feasible. Case studies from other transit agencies across the county have revealed that public-private partnerships (P3s) not only can be successful for MARTA, but they also can reduce costs and increase chances of receiving Federal funding for expansion projects.

Of the numerous project delivery methods obtained from prior research and case studies, Design-Bid-Finance and Maintain (DBFM) was deemed to be the most appropriate method for both I-20

© ASCE 2014

East HRT and Georgia 400 HRT, and Design-Build-Operate-Finance and Maintain (DBFOM) was deemed to be the most appropriate delivery method for Clifton Corridor LRT. It was found that these alternative strategies would provide significant time and cost savings over traditional delivery methods.

According to a preliminary financial plan of the projects, the capital costs of Clifton Corridor LRT, I-20 East HRT, and Georgia 400 HRT are $1.19 billion, $1.65 billion, and $2.08 billion, respectively. Assuming each project would qualify for a Federal funding program that provides 50% of the necessary project costs and TIFIA financing for the local 50% share, the expansion projects would require a total local annual cost of $49 million, $56 million, and $68 million, respectively.

A variety of local funding sources also were determined for the projects. These sources cover a wide range of scales and bases, from direct state appropriations to naming rights and advertising opportunities. Evaluation criteria were applied to all possible local funding sources, and eight sources were chosen based on potential yield, equity, legality, and political acceptability. These local funding sources were then presented to stakeholders for each project, who then combined them to create a variety of funding scenarios. It is apparent that innovative project delivery and additional financial support from new public and private resources is crucial to MARTA's ability to expand its system.

References

MARTA, Recent North American Alternative Delivery Projects, FY 2013.

MARTA, Summary of Initial Findings for Preferred Project Delivery for MARTA New Starts Projects, FY 2013.

MARTA, Draft 10 Year Schedule Memo, FY 2012.

Transportation Infrastructure Finance and Innovation Act (TIFIA) Program (FTA) http://www.fta.dot.gov/grants/12861.html

MARTA, Definition and Screening of Potential Funding Sources, FY 2012.

MARTA, Comprehensive Annual Financial Report, FY 2012.

© ASCE 2014

Power for the People: Early Lessons from Utility-scale Solar Power Development in India

Dan Millison[1], Don Purka[2], and Len George[3]

[1] Transcendergy, LLC, 108 Montague Circle, Williamsburg VA 23185, PH (757) 565-2070, email: danmillison@gmail.com
[2] Asian Development Bank, 6 ADB Avenue, Mandaluyong City, 1550 Metro Manila, Philippines, PH (632) 632-6882, email: dpurka@adb.org,
[3] Asian Development Bank, 6 ADB Avenue, Mandaluyong City, 1550 Metro Manila, Philippines, PH (63-2) 632-6611, email: lgeorge@adb.org

ABSTRACT

In 2010, the Government of India announced the Jawaharal Nehru National Solar Mission (NSM), an ambitious program aimed at rapidly increasing India's solar energy utilization. The NSM's main goals are to commission 20 gigawatts (GW) of utility-scale grid-connected capacity by the year 2022 and create an indigenous concentrating solar power (CSP) industry and supply chain. In less than four years, the mission has already made significant steps towards achieving its goal, raising capacity from 30 megawatts (MW) to over 2,600 MW. Based in part on this initial success, a recent World Bank report argues that India is well poised to be a global leader in solar energy. The NSM serves as an important example of large-scale commercial renewable energy (RE) development supporting a broader goal of inclusive economic development.

This paper will discuss the NSM, describing the national development context, policy approaches and business models, and technology development. The paper will also summarize the progress of major projects, and discuss future challenges to the solar mission.

Energy Challenges and Resources

India faces a high demand for infrastructure services, especially for electricity: about one-third of the population – 400 million people – does not have access to grid-supplied electricity or other commercial energy services. According to the Integrated Energy Policy (IEP) Report of 2006, primary energy supply needs to increase by three to four times and electricity generation needs to increase by five to six times by 2031 to sustain an economic growth rate of 8%. Meeting this projected demand growth will require at least 320 GW of additional generation capacity. Of this projected demand about 260 GW is expected to be coal-fired, as India has considerable domestic coal reserves, and coal-fired power is considered to be a least-cost solution, with expected wholesale cost of production of about US$0.05-0.06 per kilowatt-hour (kWh). To this end, in 2006, the government of India (GOI) initiated the Ultra Mega Power Program (UMPP), aimed at rapidly building 20 GW of coal-fired supercritical power plants. Domestic coal production has not kept pace with recent demand growth, and imports are constrained by import terminal and

© ASCE 2014

intermodal transshipment capacity. As of early 2014, only 2 of 5 UMPP projects have been completed. Gas-fired power capacity has not filled the demand-supply gap, with domestic production adversely affected by regulated pricing; liquefied natural gas (LNG) import capacity is being expanded but will not be sufficient to make up for the shortfall in coal-fired capacity development.

Against this fossil power backdrop, conservation, efficiency, and renewable energy (RE) options offer attractive solutions to India's energy challenges. Figure 1 summarizes estimated RE potential of more than 280 GW, of which more than 68 GW has been developed (mostly large hydro and wind power). The undeveloped potential is substantial: assuming typical plant load factors for the various RE resources, electricity output would be about 980 terawatt-hours per year (TWh/y), which is about 75% of the minimum service demand of 1000 kWh/year per person; hydropower and solar represent about 66% and 9% of this potential output, respectively. Similar to coal, large-scale hydropower appears to be a least-cost solution with a wholesale cost of production of about US$0.05-0.06, but environmental permitting, financing constraints, and other infrastructure bottlenecks have limited rapid development of large-scale hydropower capacity.

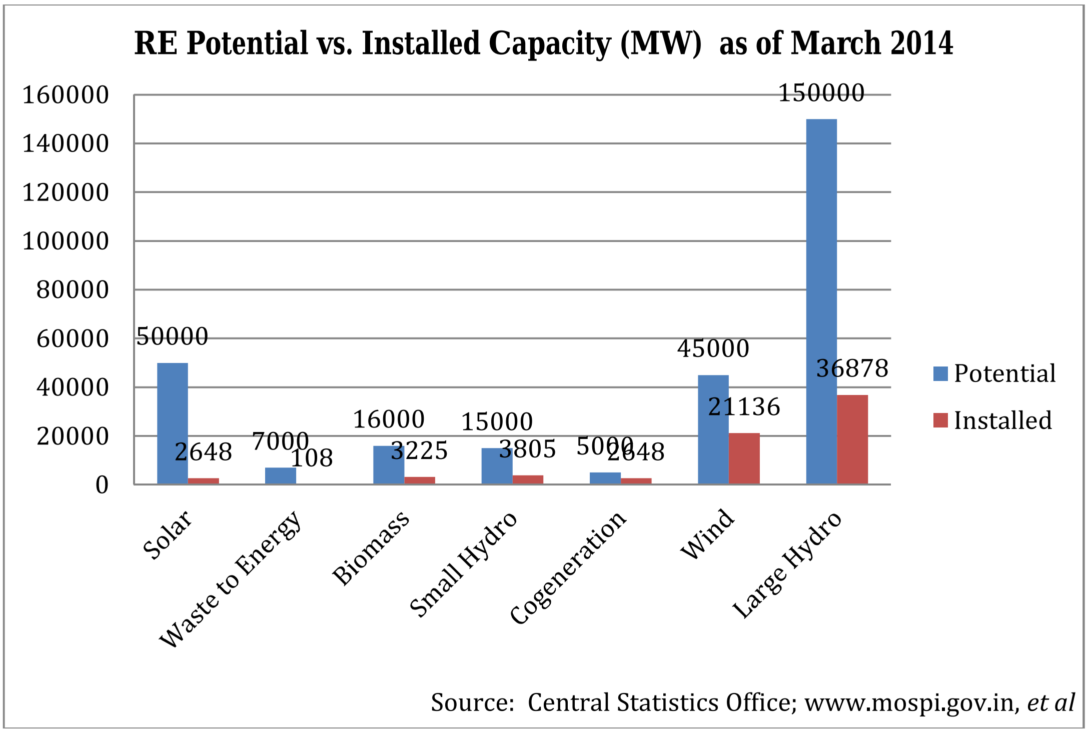


Figure 1: Renewable Energy Potential

In terms of installed capacity versus potential, wind power has been the most successful RE subsector as shown in Figure 1. Solar is the next most attractive RE resource in terms of potential energy output, and is the most flexible with respect to energy conversion technology and scalability: concentrating solar thermal power (CSP) is the most-favored technical option for electric utility operations, especially if thermal storage is incorporated; photovoltaic (PV) is the next best option for utility

© ASCE 2014

scale applications and one of the best RE options for distributed generation (DG) applications; and solar water heating is appropriate at various scales of operations from household use to industrial process heat. The scalability advantage is particularly important in the India context: solar energy is upward and downward scalable, allowing project size and conversion technology to be matched to available sites and financing. Solar PV costs have dropped rapidly during the past several years, with installed system costs approaching parity with fossil fuel plants; CSP costs are also declining but not as rapidly as for PV. As system costs decline, the financially viable solar potential increases; this learning rate, combined with other policy drivers has led some observers to believe that solar potential may be much higher than the Central Electricity Authority's "most optimistic" case of 40 GW as shown in Figure 2 (Lu Yeung, *et al*, 2012).

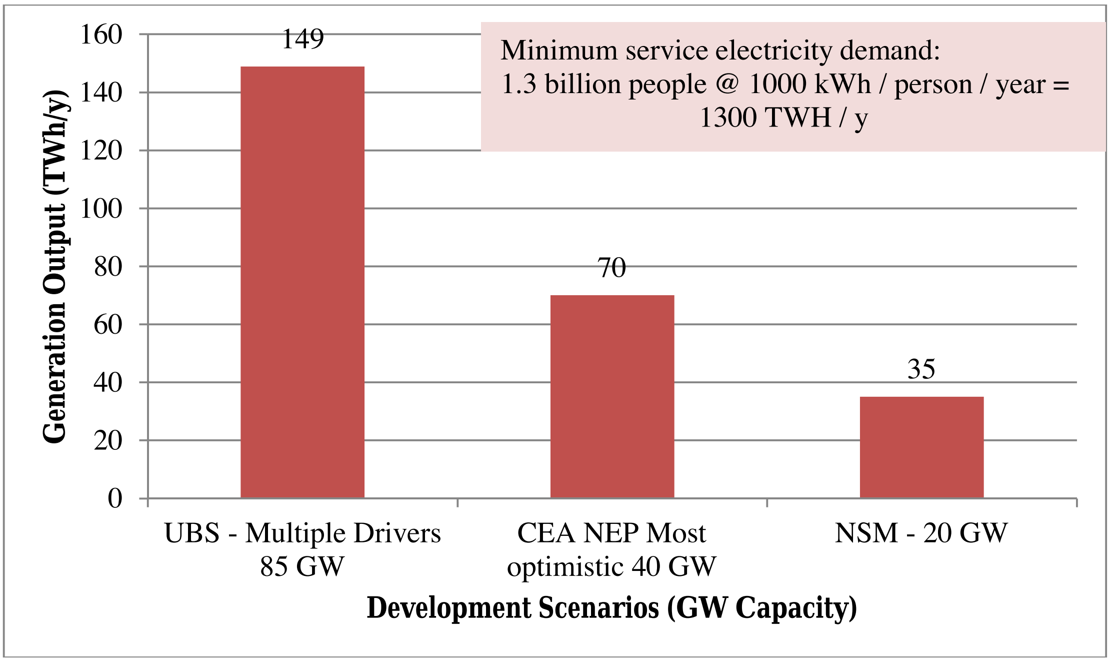


Figure 2: Solar Development Scenarios

As noted above, large-scale fossil fuel and hydropower development has not progressed in accordance with least-cost planning assumptions, and the conventional model of centralized electricity grids is clearly not meeting India's socio-economic development needs. In this literal power vacuum, conservation and efficiency improvements are needed to curtail demand, and as technology advances and RE costs decline, decentralized and distributed generation appear more competitive. India's challenges and some of the potential solutions are summarized in Figure 3.

The National Solar Mission

The national solar mission was initiated in 2008 and in 2010 the original mission was integrated into India's National Climate Change Action plan and the government announced the Jawaharlal Nehru National Solar Mission (NSM) to establish a clear vision and organizing principles. The NSM seeks to create energy

© ASCE 2014

security, mitigate climate change, improve energy technology, promote in-county solar energy development, and increase connectivity at the extremes of the energy grid. The key objective of developing 20 GW of new solar power capacity by 2022 will be achieved with utility scale grid-connected plants using CSP and PV, distributed generation with PV, and solar water heating. The NSM encourages research to support indigenous technology development and manufacturing at scale, and building next-generation plants, including solar-hybrid plants. An overarching goal is to achieve grid parity by 2022 and coal parity by 2030. The mission's timeline and goals are shown in Table 1. NSM to date has been successful, with more than 2600 MW of new grid-connected capacity commissioned as of early 2014.

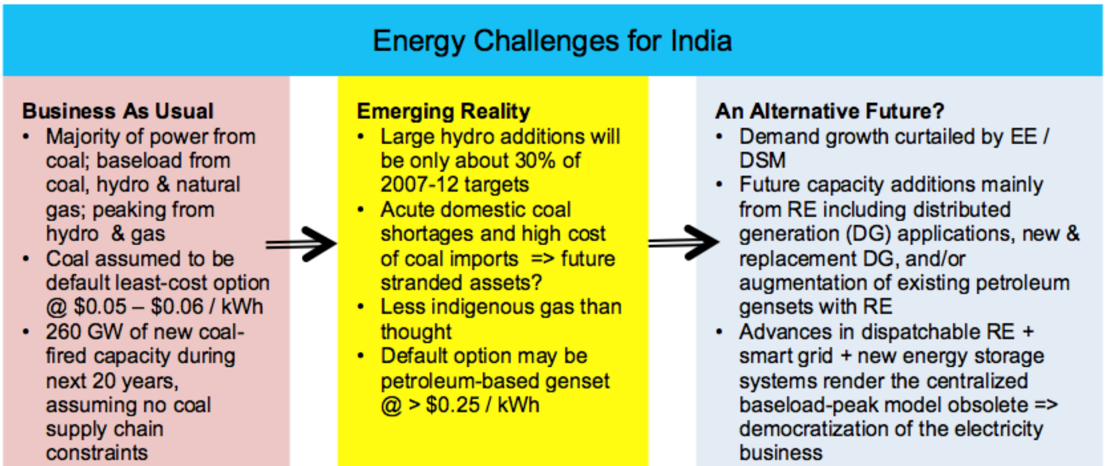


Figure 3: Energy Challenges for India

Table 1: NSM Road Map

Application Segment	Phase 1 Target (2010-13)	Phase 2 Target (2013-17)	Phase 3 Target (2017-22)
Solar collectors (thermal)	7 million m^2	15 million m^2	20 million m^2
Off-grid solar applications	200 MW	1000 MW	2000 MW
Utility grid power (including roof top)	1000 – 2000 MW	4000 – 10,000 MW	20,000 MW

In early 2011, the Central Electricity Regulatory Commission set a solar PV tariff ceiling of Rs. 18/kWh for the first batch of solar PV projects awarded through a reverse auction. More than 100 bids were submitted, well exceeding the government's hopes for private sector participation). The first batch of PV projects submitted wholesale tariff bids ranging from Rs. 10.5-12.75/kWh with an average of Rs. 12.17/kWh. Thirty PV projects of 5 MW each were commissioned under phase 1. In 2012, the second batch of PV projects were bid at an average of Rs. 8.82/kWh, a 27.5% decline (expressed in US$, the decline was not as pronounced due to depreciation of the rupee). In the course of just over 2 years, the auction process,

© ASCE 2014

along with reductions in capital costs across the industry has driven the price of solar in India to almost grid parity for peaking power.

To facilitate a prompt start, NTPC Vidyut Vyapar Nigam Ltd. (NVVN), a subsidiary of the National Thermal Power Corporation Limited (NTPC), has acted as the single buyer for solar plants connected at 33 kilovolts (kV) or higher for up to 1,000 MW of aggregate capacity. NVVN bundles power output with unallocated shares from NTPC's central power pool at a 4:1 ratio, which dilutes the cost of solar power to the end-consumers. For the phase 1 projects, the average bid of Rs. 12.17/kWh bundled with NTPC unallocated shares at Rs. 3/kWh yielded a bundled rate of Rs. 4.5/kWh, compared to grid parity of Rs. 7/kWh for baseload and Rs. 8.5/kWh for peak power, and diesel generation at ~ Rs. 15/kWh. This method of bundling tariffs combined with reverse auctions for generation projects obviates the need for feed-in tariffs (FiTs), concessional finance, and explicit subsidies from the central government.

Although bundling is an effective way to reduce the price impact on end-users, the approach is constrained by a limited amount of unallocated NTPC power and beyond the initial block of 1000 MW solar tariffs will be passed on directly to consumers. Concessional financing and/or subsidies may be needed to bridge the gap until the levelized cost of electricity (LCoE) from solar plants reaches grid parity; low-cost long-term debt financing may be the best avenue for public policy support (Stadelmann, et al, 2014a). India has limited public sector fiscal depth to sustain retail price subsidies. Prime Minister Modi's new government will likely adopt policies that were successful in Gujarat, namely moving the electricity sector to fully commercial operations while limiting subsidized retail consumption. The Modi government has consolidated the former ministries of Coal, New and Renewable Energy, and Power into a single ministry, and has signaled clear intent to streamline India's notorious bureaucracy with the theme of "less government, more governance."

State Programs and the Solar Park PPP Model

The NSM appears to be on track to achieve the 20 GW objectives: with more than 2 GW of new capacity already installed some market observers have predicted accelerated development of up to 85 GW by 2022-23 as shown in Figure 3 (Lu Yeung, *et al*, 2012). There are multiple programs and policy drivers including renewable purchase obligations (RPOs), a relatively new program for tradable renewable energy certificates (RECs), and an edict from the Department of Telecommunications to convert remote telecom tower operations from diesel-fired generation to solar power. Although these programs and policies apply to the entire country, the states of Gujarat and Rajasthan account for most of the installed utility-scale capacity due in part to aggressive state-level programs including solar parks (these states also have excellent solar energy potential in terms of insolation rates).

The solar parks concept is to support large-scale generation assets developed by the private sector, in a variation of the industrial park business model developed under state energy department and utility company leadership. The initial

© ASCE 2014

infrastructure development by public sector entities is intended to reduce private sector project development risk, so that the individual solar power plants can be “dropped in” to the park. Figure 4 illustrates the solar park model (which was developed in part on the UMPP experience which combined public-private partnership and reverse auctions to solicit private sector investment in generation plants). The solar park concept varies from state to state, with some states, such as Gujarat, including complementary manufacturing and smart city development within the industrial park model. Other states, like Rajasthan are providing less development support upfront, and have less emphasis on common infrastructure to support private generation plants.

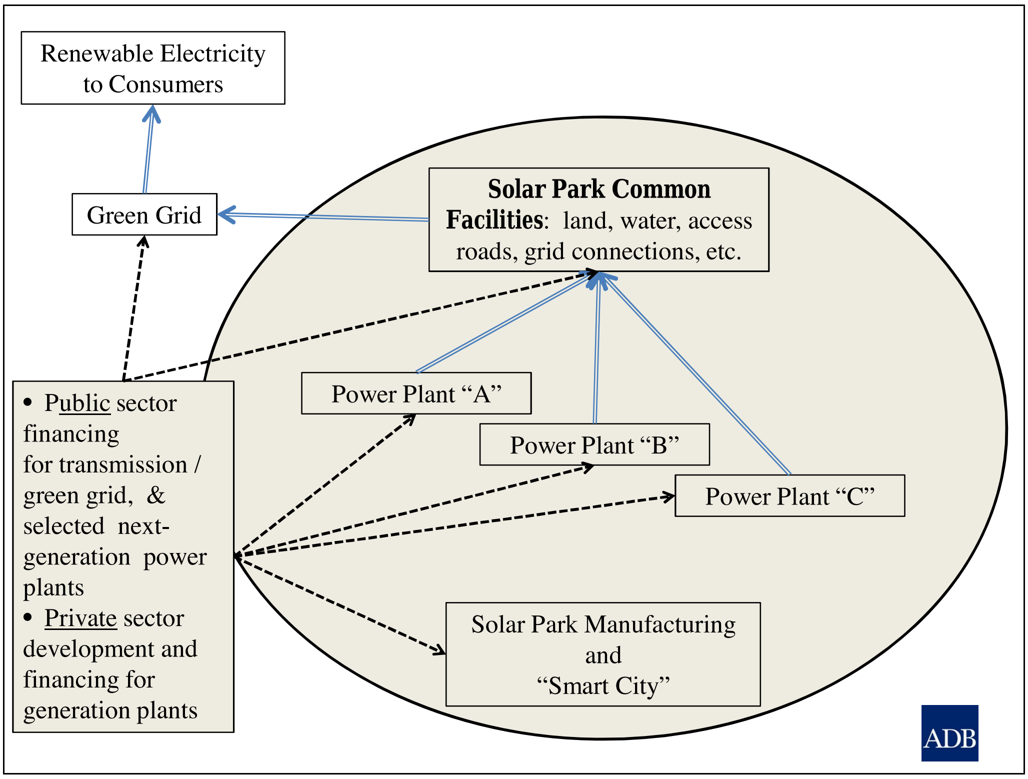


Figure 4: Solar Park PPP Model

Gujarat’s Solar Program was initiated in January 2009 with similar goals to the NSM. The program envisions four or five solar parks with at least 1000 MW of capacity each, covering 20,400 hectares (ha) of land. The solar parks comprise a mix of public and private holdings, with state-led infrastructure development including grid connections, and generation assets built with private investment. The Gujarat park plan also includes complementary manufacturing and potential smart city development. The program features 25 year power purchase agreements (PPA) with Gujarat Urja Vikas Nigam Ltd. (GUVNL), a state holding company for electric utilities. Projects commissioned before 2014 avail of FiTs, an exception compared to most other solar projects in India. The FiTs are set at Rs. 12/kWh for PV and Rs. 9/kWh for CSP for a period of 12 years; the FiTs drop to Rs. 3/kWh for the following 13 years [for PV, the original tariff order from the Gujarat Electricity Regulatory Commission specified Rs. 15/kWh for the first 12 years, dropping to Rs. 5/kWh for

© ASCE 2014

the next 13 years]. Any Clean Development Mechanism (CDM) benefits are shared 50:50 with distribution off-taker. Construction of the Charanka Solar Park began in December 2010, with official commissioning in April 2012, at which time 214 MW of new capacity was already installed [Asian Development Bank provided public sector financial support for the Charanka Park in 2011]. As of early 2014, Gujarat's various solar parks had an installed capacity of 824 MW, well on their way to reaching, and potentially surpassing their goal.

Rajasthan's Solar Policy was enacted in 2011 to develop the state as a "global hub of solar power" with between 10 to 12 GW of new capacity over the next decade. The project aims at achieving grid parity in 7-8 years. There are solar parks in four areas comprising of over 10,000 hectares, with each area targeting at least 1000 MW of capacity. Rajasthan's program places less emphasis on the integrated solar park scheme, with limited infrastructure support from the state, and more emphasis on the full spectrum of technology with various CSP demonstration/prototype projects (100 MW parabolic trough, 50-100 MW CSP with storage, 20-50 MW central receiver with molten salt/steam storage, and a 100-150 MW hybrid solar gas/coal project). All CDM benefits are transferred to distribution off-takers. As of late 2013, installed solar capacity was 442.25 MW. Rajasthan and Gujarat have excellent wind resources as well, offering the prospect of optimizing variable output RE generation with advanced grid technology and meteorological forecasting.

CSP vs PV: Applications, Solutions, and the Race to the Cost Bottom

Transmission and distribution (T&D) utilities tend to prefer CSP because of its reliability and dispatchability. PV is a better solution for DG and "last mile" applications, with the built-in advantage of avoided T&D system losses. Both technologies have different attributes and benefits pointing to preferred applications and solutions, as well as different prospective cost reductions, as shown in Table 2. As of mid-2014, global installed CSP capacity was 3 GW versus 90 GW of PV (Stadelmann, *et al*, 2014b).

There is no simple answer as to which is "the best" technology: at the project and consumer level, it is the application and solution that matters, not the technology. Despite CSP's longer construction times and higher capital costs, it is favored by utilities because it is dispatchable (consistent with the conventional energy development approach of working from the resource toward the application and consumer). PV has obvious advantages for DG applications (working from the application and consumer back to available resources). PV is a relatively simple kit, is easy to build, and is already being manufactured in India. More advanced meteorological forecasting and more affordable energy storage systems will allow PV and other intermittent generation to become more dispatchable, and increase its commercial potential. Supplier credit business models may also facilitate rapid expansion of PV installations. Conversion efficiency is a meaningful design parameter that relates directly to plant load factor (PLF, or generation output): the

© ASCE 2014

difference between 18% and 22% conversion efficiency is 22%. Utility-scale PV projects which achieve 20% PLF in routine operations should be competitive.

Table 2: Solar Power Technologies: Applications, Solutions, and Costs

Issues	PV	CSP
Hardware	simple, with few moving parts, i.e. "plug and play"	complex, requires precision design and engineering
Site Preparation	less precision, up to a 5% slope	precision required, less than 1% slope
Construction Time	less than one year	two years, best-case
Modularity	built in, ideal for DG applications	limited except for dish engine and modular towers
Domestic Production/Cost Reductions	potential mass production of key components driving rapid cost reductions	nascent capacity, relies on traditional economies of scale for cost reductions
Baseload Requirements	smart grid and advanced storage needed for quasi-baseload operations	integrated thermal storage to approximate baseload operations
Dispatch	Baseload vs. load following vs. peaking: does it matter in a power deficit market? Advanced meteorological forecasting to facilitate "day ahead" dispatch	Baseload operations are traditionally preferred by utilities: CSP preferred with today's kit
Pricing	Rapid cost reductions expected to continue	LCoE of $0.10/kWh expected by 2020 based on technology trajectory
Scale vs. Speed vs. Cost	Do falling costs and rapid construction offset the perceived dispatch advantages of CSP?	Can predicted cost reductions be achieved? Still need 3-5 years to design & build large plants.
Development Approach	Consumer/Application to Resources/Technology	Resources/Technology to Application/Consumer

With the recent decline in costs, PV appears to have the advantage in the current market in India: a 2012 report on the India solar market by UBS mentions CSP only once (Lu Yeung, *et al*, 2012), and a 2012 report on the global solar markets by McKinsey does not mention CSP at all (Aanesen, *et al*, 2012). The cost comparison between PV and CSP is not trivial, as the NSM supports creation of an indigenous CSP industry and supply chain, with the objective of expanding CSP manufacturing capacity to drive down the installed system cost. The technical reality is that the CSP kit is more complex than the PV kit, which begs the question: can CSP be built at "Model-T prices" by scaling up hardware production, or is "Tesla X" the best price we can expect? India's NSM is notable in that 3 CSP projects have levelized investment costs below US$0.20/kWh, which are the lowest in the world

© ASCE 2014

(based on project information compiled in a detailed discussion on CSP cost reduction prospects by Stadelmann, *et al*, 2014a). A recent review of the NSM (World Bank, 2013) highlights a key aspect of the global CSP business which poses a serious challenge to India's long-term objective of building up an indigenous CSP industry:

> "Solar thermal technologies continue to suffer from immature manufacturing value chains and have not been able to achieve sufficient scale to drive down costs. The solar thermal industry is made up of oligopolies led by technology developers who also own significant portions of the supply chain. Most technology developers have created their unique, patented products and segments of the value chain with alternative uses [for example, heat transfer fluids were globally in short supply in 2012 resulting in a spurt in their prices], and experience periodic capacity gaps and volatility in prices."

Notable Project Development to Date and Financing Issues

As of early 2014, more than 2 GW of utility-scale solar power capacity had been commissioned across India, most of which are PV installations of about 5 – 25 MW. Many of these projects were conceived as CSP plants but developers opted for PV due to rapid recent cost declines. India's development "space" in general and the solar parks in particular, are large enough to host the full spectrum of technology development, with 3 notable projects warranting further discussion. Table 3 summarizes these 3 projects in India and 2 other landmark projects in Africa and Latin America with respect to capacity, installed costs, and estimated LCOEs.

Table 3: Recent Landmark Solar Projects

Project / Technology	Capacity (MW)	Total Cost ($)	Estimated LCOE ($ / kWh)
Morocco Ourzazate / Trough with 3 hours storage	160	2.8 billion	0.19
Chile Atacama / Tower with 8 hours storage	50	425 million	[to be determined after tendering]
Reliance Power / CLFR	100	415 million	0.21
Dahanu / Thin film PV	40	147 million	0.36
Acme Bikaner / modular towers (eSolar)	10	29.9 million	n/a

In India, one of the largest PV plants is the Dahanu 40 MW thin-film project supported by Asian Development Bank's (ADB) Private Sector Operations Department (ADB-PSOD). The largest CSP plant under development is the Reliance 100 MW concentrating linear fresnel reflector (CLFR) project, also by supported by

© ASCE 2014

ADB-PSOD. The Reliance project is the largest solar project in Phase I of the NSM, the largest CSP project in Asia, and is currently the world's largest CLFR project. In the NSM context, the Reliance project is important as 60% of the solar field components were manufactured locally, contributing to the indigenous technology and supply chain objectives.

The Acme Bikaner project in Rajasthan is the world's second project to utilize the modular tower system pioneered by eSolar. The first 2.5 MW module was commissioned in 2010 (details on build-out to the full 10 MW are unavailable as of early July 2014). The modular design concept is notable as it is intended specifically to deliver CSP in "Model T" mode: eSolar of California was founded by former information technology (IT) professionals with an interest in quantum advances in RE commercialization, and operates on the concept of merging IT and advanced energy technology; these foundations match up well with India's potential competitive advantages in solar development.

Installed costs on the projects shown in Table 3 vary dramatically, which is to be expected based on the variety of technologies and project scale. The modular tower system has the lowest installed cost of approximately $3/watt, while the projects with thermal storage are estimated at $8.5/watt for Atacama (Interamerican Development Bank, 2012) and $17.5/watt for Ourzazate (Falconer, *et al*, 2012). The Reliance and Dahanu projects are at the lower end of the range with $4.15 per watt and $3.68 per watt, respectively. The LCOEs should be viewed with caution as these are site-specific and will vary with the cost of financing: the 3 projects in India are being financed on a commercial basis, while the projects in Chile and Morocco enjoy substantial concessional financing from various donors and the Clean Technology Fund. It remains to be seen whether a large CSP project like Ourzazate can achieve LCOE of less than $0.20/kWh without concessional financing. [The $0.20/kWh benchmark is noted as this was the average of tariffs bid for 7 CSP projects in NSM phase 1.]

In addition to the Reliance and Dahanu projects, ADB-PSOD has provided financing for 145 MW of PV projects developed by Moser Baer in Rajasthan. ADB's public sector operations have provided technical assistance in support of the NSM, and sector loans for grid expansion in Gujarat and Rajasthan. In 2013, ADB's Board of Directors approved a $500 million financing program, including $200 million of concessional loans from the Clean Technology Fund, for Rajasthan's transmission system expansion that will connect at least 4 GW of solar and wind capacity to the state and national grids (this is the largest known concessional financing contribution to the NSM).

Outlook: "A New Hope"

Phase one of the NSM has progressed well. Most of the capacity additions have been in the 5 – 20 MW range, avoiding the "too big to succeed" syndrome, relying on commercial investment with minimal subsidies and donor support. Going forward, the main challenge is to accelerate development of new capacity. If installed

© ASCE 2014

costs for CSP and large-scale PV average around \$3/watt, an additional 18 GW of capacity by 2022 translates to more than \$6 billion per year of investment which is expected to come from commercial sources. New projects will continue to face various risks including financing (local versus foreign currency and attendant exchange rate hedging risks), bankability of power purchase agreements (off-take risk), transmission evacuation and dispatch risks, technology performance risks (especially for CSP), and policy support (e.g., via the REC and RPO mechanisms). Mitigation of all of these risks is critical for attracting private capital: investors want "TLC" – transparency, longevity, and consistency. The question for skeptical investors is not whether money can be made from the Indian sun (Lu Yeung, *et al* 2012), but whether money can be made in India at all? As noted above, the new government of Prime Minister Modi has already taken steps to improve energy sector governance. Public sector support for renewable energy development is expected to continue, but most likely using the organizing principle of "precision-guided" subsidies.

Conclusion

India's solar program is the largest of its kind in a developing country and has made significant progress over the last several years. The NSM provides a clear vision and organizing principles: energy security, climate change mitigation, technology leap-frogging, indigenous solar industry development, and last-mile and bottom-of-the-pyramid connectivity. India appears on the cusp of becoming a global solar technology leader by taking advantage of research capacity, an evolving manufacturing base, favorable policy environment driven by energy security needs, and program and project scale. India's long-term success depends on the ability to fully commercialize the manufacturing base and supply chains including after-market services, and ultimately on the ability of India-based enterprises to compete in the global market against counterparts from Australia, China, Europe, the US, and the United Arab Emirates. Considering the lack of progress in expanding conventional fossil power capacity, the question is not whether India's solar program will succeed, but rather how successful will the full spectrum of energy efficiency and renewable energy development be?

References

Aanesen, Krister; S. Heck, and D. Pinner. 2012. *Solar Power: Darkest before dawn*, McKinsey on Sustainability and Resource Productivity, April 2012.

Central Statistics Office, National Statistical Organization. 2012. Energy Statistics 2012; Ministry of Statistics and Program Implementation, Government of India; wwmsopi.gov.in

Falconer, Angela, & Gianleo Frisari. 2012. *San Giorgio Group Case Study: Ouarzazate I CSP*, Climate Policy Initiative, August 2012.

© ASCE 2014

Inter-American Development Bank. 2012. *Chile CTF-IDB Concentrated Solar Power Project*, IDB Private Sector CTF Proposal for Submission to the CTF Trust-Fund Committee; approved on 11 September 2012.

Lu Yeung et al. 2012. *Can money be made from the Indian sun?*, UBS Investment Research, India Solar Industry, 16 April 2012.

Stadelmann, Martin; Gianleo Frisari, and Anja Rosenberg. 2014a. *The Role of Public Finance in CSP: Lessons Learned*. San Giorgio Group Brief / Climate Policy Initiative; Climate Investment Funds, Washington, D.C.

Stadelmann, M.; G. Frisari, R. Boyd, and J. Faes. 2014b. The Role of Public Finance in CSP: Background and Approach to Measure its Effectiveness. Venice: Climate Policy Initiative.

World Bank. 2010. *Unleashing the Potential of Renewable Energy in India*. South Asia Energy Unit, Sustainable Development Department, World Bank. Published by World Bank Energy Sector Management Assistance Program (ESMAP).

World Bank. 2013. *Paving the Way for a Transformational Future: Lessons from Jawaharlal Nehru National Solar Mission Phase I*. World Bank Energy Sector Management Assistance Program (ESMAP).

© ASCE 2014

Public Transport in Dhaka: Organizational, funding and Financing Issues for Sustainable Development

Md. Shoaib Chowdhury, PhD, PE, M.ASCE [1]

[1]Adjunct Associate Professor, Department of Civil Engineering, The City College of New York, 160 Convent Avenue, New York, NY 10031; PH (201)-963-4136; email: mchowdhury@ccny.cuny.edu

ABSTRACT

With over 15 million inhabitants in an area of some 360 sq-km, Dhaka emerges as one of the rapidly growing, densely populated, congested, and polluted mega cities in the world today. Dhaka's transportation system is road based and transport infrastructure is substantially inadequate with approximately 7 percent land dedicated to transport infrastructure. Despite there exist tremendous demands for public transportation services, Dhaka is poorly served by only bus based system; and government has yet to articulate strong policies, regulations and investment commitments in this sector. The Bangladesh Road Transport Corporation (BRTC), a poorly funded government agency, provides bus service covering only a small area of the large metropolis. Privately owned and operated bus transit providers are very fragmented and unorganized small companies that provide inadequate and very poor quality of service. The resulting effect is a degraded mobility for the dwellers that severely hampers livelihoods, economic growth and productivity.

The focus of this paper is to addresses the scopes and opportunities for the government and private sectors to participate in the development of a sound public transportation system from organizational, operational and investment (e.g., funding and financing) prospective. As such, the paper critically examines various organizational settings as well as funding and financing options and mechanisms from local socioeconomic and governmental contexts, and makes recommendations accordingly. The paper suggests that the national government should focus on enacting appropriate policies and regulations to establish an umbrella organization that would ensure seamless transit service across jurisdictions and consolidate/integrate all service providers. Finally, the paper discusses the opportunities for the private transit providers to participate in the operations of routes and systems under a public and private partnership framework.

INTRODUCTION

Dhaka is the capital of Bangladesh under the district of Dhaka. Its population is some 15-million and the population continues to grow at an annual rate of 3 to 4 percent *(Muzzini and Aparicio, 2013)*. It is the administrative, economic, commercial, industrial and cultural hub of the country and contributes 36 percent of the Gross Domestic Product (GDP) in the national economy *(Muzzini and Aparicio, 2013)*. Dhaka is also one of the densely populated and fastest growing mega cities (e.g., cities with inhabitants exceeding 10-million) in the world today *(MoEF, 2012; World Bank, 2007)*.

Dhaka relies on its road based transportation system. The roads of Dhaka have never been planned well and as such, the road network is substantially inadequate. Only 7 to 8 percent of the total land is dedicated for transportation purposes as compared to some 20% to 30% in

© ASCE 2014

many cities in the developed world. Furthermore, the roads are generally very narrow and bus based public transportation system is very poor covering only a small area of the city.

Inadequate infrastructure coupled with limited and poorly served public transportation system is the major cause of chronic congestion, degraded air quality and low level of mobility, all of which makes the city dwellers' daily life very measurable. Given the limited roadway space, public transportation seems to be the most effective way to ensure energy efficient and environmentally sustainable mobility for the dwellers; Even though Dhaka is poorly served by buses (currently the only form of mass transportation mode), the bus ridership in terms of modal share is high. As posted in the Dhaka Transport Coordination Authority (DTCA) home page, the modal share in Dhaka include 5.1 percent Car, 38.3 percent Rickshaw, 19.8 percent Walk, 28.3 percent Public Bus, and 8.4 percent other modes *(DTCA, 2014)***.** With relatively well developed public transportation systems and similar socio-economic and cultural settings, the share of public transportation trips in the cities of Delhi and Mumbai of neighboring India are 43 percent and 88 percent, respectively *(Badami and Haider 2007).* This data further supports the need for a good public transportation system in Dhaka. Therefore, Dhaka must be supported by a sound public transportation system to stimulate its economy while providing dwellers with a better access to jobs, education, and healthcare and above all to perform daily activities.

The major focus of this paper is the organizational, funding and financing issues and needs towards developing a sustainable public transportation system in Dhaka. Accordingly, this paper is organized as follows: (1) a brief review of the existing systems and services, and identification of related needs, (2) a discussion of governance and institutional issues and needs, (3) a discussion of the corresponding funding and financing issues and needs, and (4) concluding remarks.

ISSUES AND NEEDS WITH SYSTEMS AND SERVICES

There are 170 bus routes on Dhaka's some 1868 km of roads. A total number of 2312 large and 3146 small buses operate on those routes *(BRTA, 2014).* The majority of bus routes are operated by private providers. Bangladesh Road Transport Corporation (BRTC), a state owned semi-autonomous body also operates buses on some 11 routes *(BRTC, 2014).* The private operators are very fragmented, unorganized small companies and individual owners often owning as small as 2 to 3 buses and as high as 30 or more buses *(Sultana, 2013).*

More than one service providers operates on each bus route without maintaining a proper schedule. Often bus drivers of different service providers compete with each other blocking roadways and creating a potential risk for accidents. Bus operators do not maintain published information on bus routes showing stops and travel paths, and schedule (time table) and operating hours etc, which discourage people who are unfamiliar with bus routes to ride on buses. Bus routes are not given any preferential treatment and thus buses operate in a mixed traffic maintaining a very slow speed. Moreover, bus routes are not integrated at network level though buses on some routes do overlap at some places. Due to poor (e.g., informal schedule and overcrowding) bus service performance, a large number of trips are made on foot (walk) and those could have been the bus riders provided a better service ensured.

There are few formal bus stops or bus shelters for passengers to wait comfortably. Passengers often wait outside on the side of streets. In addition to serving the informal bus stops, buses also pickup and drop off passengers at any point along the route at the discretion of the driver or conductor. Competing bus operators often dispatch more buses along high demand routes then that are operationally feasible, that intern creates bus bunching problem (e.g., uneven headway), and eventually more congestion. Contrary to high demand routes, operators are reluctant to serve low demand routes increasing the user's frustration and wait time. This is due to the fact that there is no strong regulation and enforcement from the part of regulatory agency (e.g., Bangladesh Road Transport Authority) in regards to the service performance and service schedules. However, without a strong transit policy while addressing the issues such as funding, financing, and subsidies, systems and service planning, organizational and regulatory measures, it would be difficult to motivate the profit oriented and loosely formed private providers to improve transit service quality and expand service area coverage in an effort to meet the travelers needs. As such, in its current form, private providers with the goal of maximizing profit rather than meeting social obligations are unable to ensure sustainable development practice.

In an effort to improve public transportation system in Dhaka, World Bank (WB) and Japan International Cooperation Agency (JICA) have been providing some assistance to the government of Bangladesh. Notably, World Bank has financed the completion of feasibility study and preliminary design of a 22-kilometer long (16-station) Bas Rapid Transit (BRT) line. Dhaka Transport Coordination Authority (a regional coordination authority for transportation developments) has been involved in studying a 20.1 km long (16-station) Metro Rail Transit line that would potentially be built with the assistance of Japan International Cooperation Agency (*DTCA, 2014*). Upon completion of the Metro Rail Transit line, a newly conceptualized government agency named Dhaka Mass Transit Company Ltd (DMTCL) will take control of its operation, management, and maintenance related responsibilities (*MoF, 2013*). However, history shows that often foreign funded projects are cancelled or delayed for many different reasons. There is some doubts whether the project will eventually be built or if yes, then when.

Given its population density, city size and narrow roadways, Dhaka needs a high capacity faster mass transit system that is affordable to its low income and poor dwellers. Particularly, this paper proposes the development of an integrated multimodal public transportation system by well connecting the high speed transit lines or network (e.g., BRT, LRT, Metro Rail etc) with feeder route networks (e.g., bus, taxi, rickshaw-a non-motorized mode etc.).

ISSUES AND NEEDS WITH GOVERNANCE AND ORGANIZATIONS

In this section, local governance and institutional issues are discussed. Major government agencies directly or indirectly involved in transportation related activities are reviewed (see Table 1). Lastly, a proposed transit agency capable of providing a comprehensive service is defined and characterized.

Among the agencies, Dhaka Transport Coordination Board (DTCB) was established under an act in 2001 to coordinate the formulation of long range transportation plan, infrastructure development and traffic management activities in the Dhaka Metropolitan Area (DMA) and its peripheries. In 2011, through an amendment to act 2001, DTCB was renamed as the Dhaka Transport Coordination Authority (DTCA) giving additional responsibility to coordinate the formulation of plans and implementation of regional mass transportation systems in a more wider area (e.g., 7,440 square kilometers) encompassing six districts (e.g., Dhaka, Narayanganj, Munshiganj, Manikganj, Gazipur and Narsingdi) (*DTCA, 2014*).

The Bangladesh Road Transport Authority (BRTA) was established in 1988. It is the national regulatory agency that ensures safe operations of traffic across the country. Its responsibilities include issuing vehicle registration and fitness certificates, and driver licenses as well as regulation of bus fare. BRTA also formulates the National Land Transport Policy and National Road Safety Strategic Action Plan *(BRTA, 2014; MoF,2013)*.The Bangladesh Road

© ASCE 2014

Transport Corporation (BRTC), under the ministry of communication, was created in 1961 under the ordinance No 7. BRTC operates inter-district and regional buses as well as a limited number of buses in Dhaka city *(BRTC, 2014)*. It also provides truck based nationwide cargo service. Due to shortage of manpower, often BRTC leases its buses to private bus operators. Given its institutional weaknesses and wider obligations at national level, it is incapable of providing a sound public transportation service for the dwellers of Dhaka.

Table 1. Selected Government Agencies with Transport Related Responsibilities.

Agency	Key Responsibilities	Jurisdiction		Ministry Affiliation
		Boundary	Area (Sq-Km)	
DTCA (Formarly DTCB)	Coordination of Transport Policies and Planning; Coordination of the Implementation of Regional Mass Transportation System	Dhaka, Gazipur, Narsinghdi, Manikganj, Munshiganj and Narayanganj Districts	7440	Communications
BRTA	Regulation, licensing, Bus Route Permits	Entire Bangladesh		Communications
BRTC	Inter-district and Regional Bus Operations; Bus Operations on Selected Dhaka City Streets	Entire Bangladesh		Communications
RAJUK	Land Use and Development Plans; Physical Infrastructure Growth Control	DMDP Area (DCC area and five other nearby pourashava areas of Gazipur, Tongi, Savar, Narayanganj and Kadamrasul)	1528	Housing and Public Works
DCC (DNCC, DSCC)	Infrastructure maintenance, and Tax and Fee collections	Core city	360	Local Government, Rural Development and Co-operatives

Dhaka City Corporation (DCC), under the ministry of Local Government and Rural Development (LGRD), is responsible for administering and managing the city properties and collecting taxes and fees. In December 2011, the local government (City Corporation) act of 2009 was amended to divide the DCC into two parts: (1) the Dhaka North City Corporation (DNCC) covering the area in the northern part of the city, and (2) the Dhaka South City Corporation (DSCC) covering the area in the southern part of the city *(DNCC, 2014; DSCC, 2014)*. Similar to other agencies, DCC has been suffering from serious institutional weaknesses in terms of governing authority and organizational capacity to formulate policies, planning and operations procedures, as well as to develop standard practices, organizational culture and values. For instance, it has a very weak traffic department (from both technical tools and skilled manpower prospective) which cannot design traffic signal timing plan without the support from consultants.

RAJUK (a semi-autonomous body for land control and development), is responsible for managing the growth and development within the Dhaka Metropolitan Development Plan Area (DMDPA). It approves industrial, commercial and residential development projects *(RAJUK, 2014)*. However, due to its weak policy and planning laws, and enforcement capacity, RAJUK has failed to perform its responsibilities *(Chowdhury, 2008)*. A large number of infrastructures (e.g., residential, commercial and industrial buildings) in Dhaka city are illegal. As Chowdhury *(Chowdhury, 2008)* indicated, more than 16000 high rise buildings have been constructed in

© ASCE 2014

Dhaka without taking approval from RAJUK indicating that a large percentage of the total construction activities (land development) in the city are illegal.

There is a strong interaction between transportation and land use. Yet, there are no coordinated and integrated policies and plans for land use and transportation in Dhaka. For instance, RAJUK is responsible for implementing and enforcing the land development policies and plans, while DTCA is responsible for coordinating the development of transportation policies and program. Land use and development (structured plan and zoning) plans are made by RAJUK independently without considering its impact on transportation systems and services. In recent decades, many educational institutions (e.g., private universities) were built without giving due considerations on how these developments will have impact on transportation system, how such institutions will meet their transportation needs, what improvements will be needed from transportation systems and services prospective to accommodate new demands and so on. Today, the city dwellers are paying the price as those developments are partially responsible for chronic roadway congestions and subsequent air pollution.

As shown in Table 1, each of all government agencies (e.g., DTCA, DCC, BRTA, BRTC and RAJUK) are centrally controlled and vertically aligned long respective ministry *(Rahman, 2013).* And, thus, none of the local agencies enjoy full autonomy meaning that a local agency cannot independently make its own decisions with respect to budget and spending, employee training and creating strong functional departments, fund generation, and development policies and programs without approval from the central government through respective line ministry. Although agencies formulate their respective project proposals, however, decisions relating to the infrastructure development projects including public transportation projects are made centrally with the help of Planning Commission (PC) that reviews and recommends projects that are in line with the government's socio-economic development goals on a priority basis. All approved projects are funded through fiscal (annual, June-July) budget under the program called "Annual Development Program (ADP)".

Due to strong central control, these institutions have been failing to take leadership role, raise funds or look for alternative financing sources and mechanism, and create technically sound function departments toward meeting the sustainable development challenges. Furthermore, at present, there is no transit agency in Dhaka city to take the public transportation service responsibility. Given the existing centrally aligned institutional settings, it is unlikely that change will take place immediately. However, for such a mega city that is rapidly growing and merging with the neighboring municipalities (See Fig. 1), a fully autonomous regional public transit agency would be needed to provide a seamless service crossing the jurisdictional boundaries. The agency should be given the authority to formulate policies and programs with its own budget and revenues, impose taxes in areas with transit developments, engage in Public-Private Partnership (PPP) agreements with the private entities, take loans, as well as to participate in non-transportation development projects with private sectors. It should be given the responsibility to operate and manage public transit service, and to coordinate and monitor private providers. Both the central and local governments should also commit to provide sustained fund to the agency until it becomes financially self-sustaining.

As such, this paper proposes that a fully autonomous regional transit agency should serve the Dhaka Metropolitan Development Plan Area (DMDPA) which is under RAJUK's jurisdiction. Such an agency is needed not only to address the existing public transportation problems but also to develop regional transit system for a seamless and integrated service across multiple jurisdictions. As an umbrella agency, it will be in a better position to make regional

© ASCE 2014

transit planning, develop integrated regional transit network, coordinate and manage service planning, and consolidate the fragmented private providers. The resulting effort will improve transit service and reduce roadway congestion.

The DMDPA (See Fig. 1) includes the DCC area and the areas of five other nearby municipalities (Pourashava's) including Gazipur, Tongi, Savar, Narayanganj and Kadamrasul. Collectively, this area represents the Dhaka metropolitan city that is rapidly expanding. Given that there are six local governments within the region, the regional transit agency has to coordinate and collaborate with all of them (e.g., DCC, and five other municipalities) as well as with other agencies directly aligned with central government such as RAJUK (potentially supporting transit oriented development), DTCA (Potentially coordinating regional policies and planning), BRTA (possibly serving as regulatory body to ensure transit safety, service quality, fare, and other socio-economic issues). Coordination would also be required with other government agencies such as agency under the ministry of environment. Figure 2 shows the framework how the regional transit agency will coordinate and collaborate with the local and central agencies.

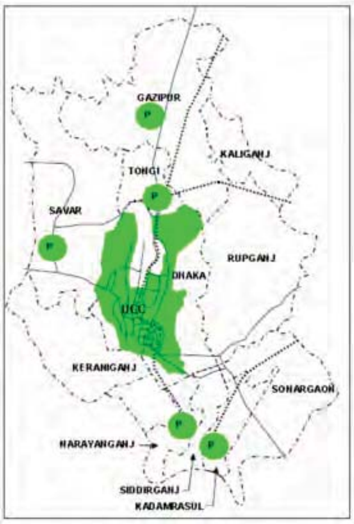


Figure 1. Local Governments within the DMDPA (Source: *DTCA, 2005*)

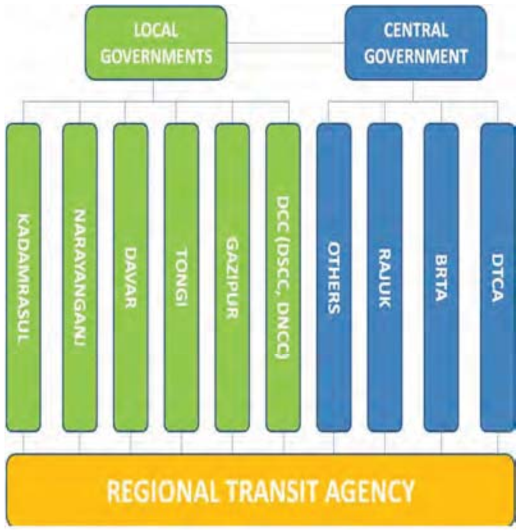


Figure 2. Framework for Agency Coordination and Collaborations

ISSUES AND NEEDS WITH FUNDING AND FINANCING

As mentioned in the previous section, in Bangladesh, infrastructure projects are planned centrally by the Planning Commission (PC), a central planning agency, and all approved projects are included in the Annual Development Program (ADP) for funding through fiscal budget. In each fiscal year, a fund is created to implement all approved projects. The ADP is a consolidated fund comes from both the government and international development partner (e.g., World Bank, Asian Development Bank, International Monitory Fund etc) sources. The major steps involved in the approval of projects are as follow *(Chowdhury, 2014):*

- ✓ Project ideas/needs are generated from various sectoral plans, five year plan and poverty reduction strategies.
- ✓ Each executive agency closely works with the affiliated ministry in the development of project proposal (DPP)
- ✓ The ministry reviews/assess the DPP

© ASCE 2014

- ✓ The DPP is then sent to sector divisions of the planning commission for the evaluation of project
- ✓ Upon recommendation for the approval from the Project Evaluation committee (PEC), the minister for planning approves the project (if the project cost is no more than TK 25 Crore), or Executive Committee of National Economic Council (ECNEC) approves the project (if the project cost is over TK 25 Crore)

However, the ADP funds are very limited and projects are selected based on the national priorities rather than the local needs and priorities. Thus, the ADP fund would be merely very small as compared to the amount that would be needed for the regional transit agency to develop transit infrastructures (LRT, BRT, Metro-Rail etc based on a comprehensive plan). In addition, there is no guaranty that system operations and maintenance cost will fully be recovered from the fare-box and other incomes (e.g., station area rent, advertisement on transit vehicles and stations etc). Thus, other possible funding and financing sources need to be explored.

Access to sources of funds and finance also depends on the agency's legal authority and potential scope for raising such funds and finances. Assuming that a fully autonomous transit agency would be established, the potential funding and financing sources are identified next from the local context. As shown in Table 2, the regional transit agency has two potential local revenue sources to generate funds besides fare-box revenue. As reported by Chowdhury *(Chowdhury, 2014)* income tax and profit, and value added tax are the two high yield tax revenues for the government. Furthermore, both of the revenues are exponentially growing with very stable long term prospect. The fund can be collected by the central government (e.g., National Board of Revenue) or the local government through an appropriate legislation.

Table 2. Potential Funding Sources for the Regional Transit Agency

Category of Fund	Potential Source or Opportunity for Engagement	Collection Authority	Collection and Distribution Mechanism
General Taxes and fees	Income Tax and Profit, Vaue Added Tax	Central or Local Governments or both	Earmarked or Annual allocation thorugh ADP
Various forms of Transit Development Impact Fees (Value capture, Special assessment district, Tax increment financing districts and so on)	Areas around transit stations and corridors	Regional Transit Agency	Direct transfer

Given the rapid growth of the city, there is a very high prospect for real-estate developments in and around transit station areas as well as long transit corridors *(REHAB, 2012).* With appropriate legislation and authority, the regional transit agency can able to impose various forms of transit development impact fees and taxes. Such fees and taxes are widely used by transit agencies and local authorities in various cities across the world *(TRB 2009, Cervero and Kang, 2011; Medda, 2012; Mathur and Smith, 2013).* Cervero and Kang *(Cervero and Kang, 2011)* found that land value increases as a result of regular bus service converted to a BRT in Seoul, Korea with certain distance of BRT stops suggesting that value capture tools could be a good source of raising fund for transit.

© ASCE 2014

The potential financing sources are broadly categorized into four groups (See Table. 3). Given that Bangladesh government currently does take loans from multilateral banks (e.g., World Bank, Asian Development Bank) and international and local bank and non-bank sources (e.g., JICA, SIDA, IDCOL), such opportunity could be taken by the regional transit agency directly rather than getting it through the ADP. As mentioned earlier, an appropriate legislation can able to facilitate such an opportunity. The direct negotiation will help the transit agency to make better policy and planning decisions since it does not need to compete with other sectors and government priorities (that is the case under the ADP funds). Other form of financing sources could be to issue various kinds of bonds including revenue and general obligation bonds. Although, generally all citizens could participate, however, expatriates remittance fund seems very promising for investment in bonds. For instance, expatriates net remittance totaled US $12.8 billion in fiscal years 2011-12 *(MoF, 2013)*.

Table 3. Potential Financing Sources for the Regional Transit Agency

Category of Finance	Potential Source or Opportunity for Engagement	Collection or Engagement Authority	Collection and Distribution Mechanism
Loans from multilateral, international and local banks	World bank, Asian Development Bank, Japan International Cooperattion Agency (JICA), Infrastructure Development Company Limited (IDCOL), Swedish International Development Cooperation Agency (SIDA) etc	Regional Transit Agency	Direct Negotiation
Bonds (e.g., General obligation and revenue)	Citizens and expatriates remittance	Local government (General obligation) and Transit Authority (revenue)	Direct transfer
Public Private Partnership (Transit system and service related)	Service contracts, management contracts, lease contracts, Design-build (DB), build-operate-transfer (BOT), Design-build-finance-operate (DBFO), build- own-operate (BOO), Build-Own-Operate-Transfer (BOOT), design-build-operate (DBO), rehabilitate-operate-transfer (ROT), concessions, and joint ventures	Regional Transit Agency	Direct Negotiation
Public Private Partnership (Non-transportation Development)	Commercial and residential developments around transit stations and along transit corridor jointly with REHAB	Regional Transit Agency	Direct Negotiation

Another potential source of finance could be to attract private funds by well encouraging local and international investors to participate in providing the transit service through public private partnership (PPP) agreement *(Chowdhury 2011)*. The PPP was found to be very beneficial in the development of public transportation infrastructure and services (e.g., BRT, LRT etc) in many Latin American and Asian cities such as Bogotá, Santiago, Seoul, and some other cities in China and India *(Christopher Willoughby 2013)*. It is also possible to consolidate all current transit providers to form a large company under the PPP program and such a company may be given to operate one or more routes (e.g., bus, LRT, BRT etc) or systems under a stronger regulations to ensure high quality, safe and reliable public transit service.

© ASCE 2014

It may also possible that some routes or a subsystem (such as all bus routes in one jurisdiction such as in DCC jurisdiction or any one of the five municipalities jurisdiction) could also be operated under a quasi-private company with a 51 percent or more government share. Such an engagement would not only provide access to private fund but also provide an opportunity to manage the systems and services more efficiently while taking private skills and talents. Such an arrangement does exist in some German and other European cities *(Vuchic, 2005).* Furthermore, the regional transit agency should also look for non-transportation developments (e.g., real-estate development in, and around transit stations as well as along transit corridor) opportunities. Such a non-transportation development was successful with the commercially operated transit agencies in Hong Kong *(Tang, and Lo, 2010).* Given that there remains substantial housing shortfall in Dhaka city, an arrangement with Real Estate and Housing Association of Bangladesh (REHAB) may facilitate the engagement opportunity to invest in the commercial and residential development (e.g., non transportation development in and around transit stations and long transit corridors) projects. It will help to minimize some of the financial risks involved with transit development.

CONCLUSIONS

Organizational, funding and financing issues are very critical in the development of sustainable public transportation system for any mega cities. As these three issues are interrelated they should also be addressed together. This paper reviews existing public transportation system in Dhaka city along with organizational and funding/financing issues from the local socioeconomic and governmental prospective. It is found that the existing bus based public transportation system is substantially inadequate as compared to the size of city and populations it serves. Given the poor regulations, the profit motivated and loosely formed private providers are unable as well as reluctant to meet dwellers transportation needs while improving transit service quality and expanding service area coverage. Furthermore, as the city continues to grow and merges with the other neighboring municipalities, providing a seamless transit service across boundaries creates additional challenge. To ensure integrated and seamless services across jurisdictional boundaries, this paper suggests that the national government should focus on enacting appropriate policies, and regulations to establish a regional umbrella organization for public transit services that would consolidate/integrate all service providers. The organization should be given adequate authoritative power to plan, budget, manage, monitor and coordinate transit service activities of all providers. The government should also commit to fund the organization until it becomes a financially self-sustaining agency. The major findings and recommendations are summarized below:

- ✓ Dhaka needs to develop an affordable, high speed, high capacity mass transportation system while integrating public transportation routes and networks (e.g., Metro Rail, LRT, BRT etc) with other modes (e.g., local buses, taxis, rickshaws etc.).
- ✓ Dhaka also needs a fully autonomous independent public transportation agency giving full legal power to engage in Public-Private Partnership (PPP) agreements, raise funds from a wider tax-base, and take loans etc. The agency also has to be given sufficient power to impose taxes within designated transit development areas, to engage in non-transportation development project with private sectors, coordinate and manage with private providers.
- ✓ Current Annual Development Program (ADP) based project funding mechanism is very weak and funds are substantially inadequate and unsustainable. Therefore, government should look for innovative funding and financing sources and mechanisms. Among the

© ASCE 2014

potential options includes Public Private Partnership (PPP), expatriates remittance income based finance, participation in the non-transportation development (e.g., commercial developments in and around transit stations and along transit corridors) projects jointly with real estate developers, imposing development impact fees, special district tax etc for transit projects.

ACKNOWLEDGEMENT
The author gratefully acknowledged the editing, comments and suggestions made by William A. Wallace in the improvement of the paper.

REFERENCES

Badami M.G. and Haider, M. (2007)."An Analysis of Public bus Transit Performance in Indian Cities." Transportation Research (Part-A), Issue 41.

BRTA (2014). "Home page of the Bangladesh Road Transport Authority." http://www.brta.gov.bd/, (March 7, 2014).

BRTC (2014). "Home page of Bangladesh Road Transpot Corporation." http://www.brtc.gov.bd/, (March 7, 2014).

Cervero, R. and Kang, CD. (2011). "Bus rapid transit impacts on land uses and land values in Seoul, Korea." *Transport Policy*, Issue 18.

Chowdhury K. (2008). "Land Use Planning in Bangladesh", *AH Development Publishing house*, Dhaka, ISBN:984-8360-020-9

Chowdhury Md. S. (2011). "Public Private Partnership: A Prospective in the Development of Sustainable Transport Infrastructures and Services in Bangladesh." *Proceedings of the first T&DI/ASCE congress*, Chicago, Illinois.

Chowdhury Md. S. (2014). "Funding Road Safety Programs and Projects in Bangladesh." *Proceedings of the second T&DI/ASCE congress*, Orlando, Florida (Forthcoming).

DNCC (2014). "Home page of Dhaka North City Corporation." http://www.dncc.gov.bd/, (March 7, 2014).

DSCC (2014). "Home page of Dhaka South City Corporation." http://www.dhakasouthcity.gov.bd/, (March 7, 2014).

DTCA (2005). "Parking Policy for the Dhaka Metropolitan Development Plan Area." *Dhaka Transport Coordination Authority*, Ministry of Communications, Government of the people's republic of Bangladesh, Second Draft.

DTCA (2014). "Home page of Dhaka Transport Co-ordination Authority." http://www.dtcb.gov.bd/, (March 7, 2014).

Mathur S. and Smith A (2013). " Land value capture to fund public transportation infrastructure: Examination of joint development projects' revenue yield and stability." *Transport Policy*, Issue 30.

Medda F. (2012). "Land value capture finance for transport accessibility: a review." *Journal of Transport Geography*, Issue 25.

MoEF (2012). "Rio+20:National Report on Sustainable Development", *Ministry of environment and Forests*, Government of the peoples republic of Bangladesh, Dhaka, Bangladesh.

MoF (2013). "Bangladesh Economic Review 2013." *Ministry of Finance*, Government of the people's republic of Bangladesh.

Muzzini, E. and Aparicio G. (2013). "The Path to Middle-Income Status from an Urban Perspective", *the World Bank*, Washington DC.

© ASCE 2014

Rahman, M. (2013). "Urban Governance and Informal Growth Regulation in Dhaka." *AH Development Publishing house*, Dhaka, ISBN:978-984-90486-8-8
RAJUK (2014). "Home page of RAJUK-Capital Development Authority of Bangladesh." http://www.rajukdhaka.gov.bd/rajuk/webHome, (March 7, 2014).
REHAB (2012). "A Comprehensive Study on the Real estate Sector of Bangladesh." *Real Estate and Housing Association of Bangladesh*, Dhaka, http://www.rehab-bd.org/, (March 1, 2014).
Sultana N. (2013). "Efficiency Analysis of Public Transit systems in Bangladesh: A Case Study of Dhaka City." Masters thesis, *University of Waterloo*, Canada.
Tang, S.B., and Lo, H.K. (2010). "On the financial viability of mass transit development: The case of Hong Kong." *Transportation,* Volume 37, Issue 2.
TRB (2009). "Local and Regional Funding Mechanisms for Public Transportation." TCRP Report 129, Transit Cooperative Research Program, Transportation Research Board
Vuchic, V.R. (2005). "Urban Transit Operations, Planning and Economics." John Willy and Sons Inc. New Jersey, USA.
Willoughby C. (2013). "How much can public private partnership really do for urban transport in developing countries?." *Research in Transportation Economics*, Issue 40.
World Bank (2007). "Dhaka: Improving Living Conditions for the Urban Poor." Bangladesh Development Series, *the World Bank*, Paper No. 17.

© ASCE 2014

Conservation of Historical district in Urban Construction Operations, a Step towards Sustainable Development

Karim Moosazadeh Mehrabani / Islamic Azad University – Mehraban Branch

Karimcivil2010@yahoo.com

Historical districts are one of the most valuable elements of cities which make identity for them. Elements, buildings, formation mode and traffic networks of each historical districts reflect the social life manner of the city's inhabitants. The attention and desire of new generations to know about the life manner of their ancestors and the history of primogenitors as well as getting acquaintance of other nations with history and past life of other nations and increasing development of tourism industry make us to study the history and identifying the old neighborhoods and historical places and attempt to keep and maintain them as the heritages of the ancestors and perform our duty for next generations. With regard to time pass and disregarding the old life of the valuable buildings, lack of attention to a historical texture could lead to destruction of the culture and identity of a society. Nowadays, by increasing development of tourism industry in the world and tourism-oriented economy, restorations and resurrection of historical districts have gained more attention in most countries. Improvement and resuscitation of these districts play a great role in their dynamism and survival as well as making income via attraction of tourists. Also, it is possible to use the incomes resulted from tourism industry for restorations and development of infrastructures to reach to urban sustainable development.

Also in this article, Baku's Icheri sheher and the historical city of Lahij and Agsu in Azerbaijan Republic will be introduced as successful samples in this field.

Keywords: Historical District, Urban Construction, Conservation, Resuscitation, Tourism, Sustainable Development.

© ASCE 2014

Introduction:

The proximity of historical districts and newly-built districts and the way that these two are connected to each other and also how we intervene in a historical district have always been counted as one of the most delicate decisions of official, civil engineers, and architects.

How to juxtapose a historical district with a modern district is determined through considering general policies that have been organized for the future of a city, and depending on the history of the city differs. For example, in Old City or Inner City (Azerbaijani: İçəri Şəhər) in Baku, Azerbaijan the general policy has been the modern development of city and the old district has been surrounded by fortress walls and remained completely untouched and kept its historical originality. This part of city which is sometimes referred as BakuErgi was built gradually between 11th to 19th centuries. It is located in North West of Baku gulf and is one of the best sights of Baku. In 2000 it was classified as a World Heritage Site by UNESCO.
This area of city is surrounded with walls from three sides and the other side is restricted by sea. The wall that is build around this city separates it from modern Baku. There are 5 gates on this wall which relates this area to modern part of city. The population which is living in it includes 14000 .As this city is located just near sea the climate is good, and it's a nice place to inhabit.
There are numerous architectural monuments inside Icheri sheher that each of them is traced back to a specific era. These monuments which are mostly built in Islamic, French Baroque, gothic, and classic styles are located both inside and outside the city. Inside the city there are 518 monuments including 17 mosques, one church, two grave yards, 6 caravanserais, 6 traditional bathhouses, 3 city emblems, fortress walls and 3 towers, 470houses, and 10 other monuments which are maintained separately as a historical site. These buildings have had a significant effect on Baku's city structure.55 percent of these houses were built in 19th century and 40 percent in early 20th century; however, some of them date back to 18th century and are older than other houses. There are also some private castles that trace back to 14th and 15th centuries. Icheri sheher consists of 23 alleys, 2 caravanserais, 3 springs, the bazaar, etc. the most attractive of them is Maiden Tower.
This unique complex attracts thousands of tourists every year which not only introduces Azerbaijan's culture and history but also is a big source to make money for both city and country .And this in its turn has led to city 's development in a way that all tourists are amazed. It should be mentioned that public welfare level is very high in this city.

But in a city such a Lahij historical district is not restricted by a street,so it is wellassimilated into the new districtand is in sync with it. Structures of houses of this city are divided to 3 parts: 1.old and historical buildings which are remembrances of the past. 2. Modern buildings which are built with traditional styles and materials and are identical to old houses.3. Houses which are built with concrete structures or metal structures and modern materials. In these building's facing is traditional, and there aren't tall structures. These houses are in complete agreement with city's historical and old district. The historical appearance of the city is kept.
In Lahij not only are the old buildings and historical districts kept, but also maintained of old professions such as coppersmithing, blacksmithing, tannery, saddlery, shoemaking, carpeting helped keep the old face of the city and presented it as a live museum, which in its turn attracts tourists from all over the world. And this both lets

© ASCE 2014

other nations know the culture and history of this area and also helps economic development and consequently it will lead to full-scale development of city and area. When tourists see sights, they stay in hotels, eat in restaurants, buy hand crafts, and all of these eventually help employment and economic development of the area. To this end, at first, historians and experts identify regional historical professions and then support continued professions and reactivates those are in declining.

From the ancient time, Lahij has been noteworthy for tourists and businessmen. Tourism industry has been active in this city since the time of the Russian empire. After the independence of Azerbaijan this city has been significant for both local and foreigntourists. The tourists have travelled a lot to this city.The old road on the right side of the Girdiman River, which was of very low quality, is deserted and a new road with high standards on the left side of the road is built. This new road has made the traffic much easier for both tourists and local people.

The improvement of electronic and radio communication such as telephones, cell phones, and the Internet from one side, and construction of hotels, hospitals, museums, etc. and service centers from the other side have led to enhancement of city condition for its citizens.

In addition, the historical city of Agsu that is a remembrance of the Medieval is located near new city of Agsu in Azerbaijan. This old city with the effort of cultural legacy and tourism ministry of Azerbaijan republic and “MIRAS” (MIRAS Social Organization in Support of Studying of Cultural Heritage) group, which is one of active NGOs in the field of history, has been explored by archeologist, maintained, repaired, and reclaimed. Besides, a park museum was built. The reconstruction and reclamation of this historical city not only presents its history but also leads to financial improvement of this district with attracting tourists and developing archeological tourism's network; consequently, it results in improvement of city services. This historical district has been registered in cultural legacy and tourism ministry of Azerbaijan republic list in 2010. For close knowing about that type of life in this district and according to archeological excavation continuance, tourists and visitors can participate in excavation location and then obtain experience as an honorary archeologist. This causes to incense interest of tourist referring and attraction of visitors. Also with creation of regional bower and serving eastern tea and baking traditional bread in tandoor (earth oven) the tourists will cater at this archeological district. Promenading with horse around the complex and fishing in District Lake causes visitors to feel living in ancient times. All of these factors cause financial supply, infrastructure improvement and sustainable development in district.

So in three above mentioned cases the tourism industry has improved in spite of maintenance of old buildings and historical district. If we want to classify buildings that are located in historical and old districts from the view point of technical-engineering, we will have four groups: 1. Best and valuable buildings. 2. Repaired buildings. 3. newly-built building 4. Destroyed buildings and ruins.

Besides, if we want to categories them according to their function, we can have four main groups:

Active buildings which have retained their function and originality: these buildings due to consolidation and retaining their function continue their activity.

Deserted buildings that can be used: these buildings are deserted owing to slight destruction, solvable building problems, or the feeling that they are not needed, but they can be repaired with a slight effort and improvement in order to change them to buildings with new functions. They can also be repaired to come back to life cycle with the same function.

© ASCE 2014

Buildings with a new function: these buildings which were used as houses, gardens, bathhouses, traditional gyms, etc. are deserted. Being valuable because of their architecture,they are amended and theyoperate as official and cultural buildings and traditional teahouses and so on. Reclamation and maintenance of these old buildings are a good step toward keeping historical buildings alive and active.
Destroyed buildings: these buildings either are evacuated because of serious destructions, or are left unused due to the lack of operation, or are changed to ruins due to the lack of maintenance in a way that are not repairable. These buildings don't have any valuable things to be kept. They should be reconstructed.
In general, before every construction in a historical district there must be a strategy in order to have a purposeful intervention. In one district not only should the body be kept, but also we must keep the sole of it. By sodoing the new texture will continue living completely independently after intervention.
Problems of providing city services in old districts and solutions:
The number of people who need each of public facilities must be determined by means of the capacity of similar facilities, numerical need level, and the type of them; facilities such as bathhouses, mosques, reservoirs, springs and aqueducts, private and semi-private places, proximity or location of small business centers in alleys and big business centers in markets, and finally main, public, semi-public, and privates roads. Type and number of facilities must be cared. The size of neighborhoods, road grading, the number of population, and distance from the main and central part of the city or neighborhood will determine the type, number, and needed size of these facilities. Some of usual problems in old neighborhoodsare:
The problem of parking space: narrow streets in some of neighborhoods, lack of parking spaces in houses, and lack of harmony in the height of house level with street level aresome of troubles people face while parking their cars.in order to solve this problem we can buy destroyed buildings and change them into multilevel parking lots.
The problem of providing gas supply in some neighborhoods: we cannot supply houses with gas in some neighborhoods andplaces. This is impossible due to numerous reasons such as impossibility of digging, or probability of causing danger. Gas problem puts the inhabitants of these places in trouble. In these sites the use of modern energy sources such as solar energy can be substituted. For example, a demand for energy supply of mosque air conditioner in archeological area (Agsu) have requested from Azerbaijan republic- state agency on alternative and renewable energy sources organization.
The security problem in some neighborhoods: some alleys due to narrow and dark streets, and presence of ruins in these districts might not be safe.in order to solve this problem we can make use of closed circuit cameras or guards. Also with culture improving by NGOs and cultural organizations, regional people cooperate in making easy to protect and maintain these historical districts.
the problem of narrow streets and inaccessibility of vehicles to these alleys: sometimes narrow width of these streets, and impossibility of traffic flow especially for old people, patients, and paralyzed citizens are very problematic .to solve this problem we can buy some taxis and create a taxi system inside the old district, that is special for these places. The other solution can be sale of these taxis to inhabitants with special loans. This idea was put into test in Icheri Sheher in Baku, Azerbaijan.
The problem of presenting some city services such as firefighting and medical emergencies: sometimes in some events like natural phenomenon and accidents in

© ASCE 2014

old districts due to the narrow streets, and impossibility of being on time for firefighters some irrecoverable catastrophes happen. In this case creating some small stations which can present first aid services in local clinics, building small fire stations, installing hydrants in alleys, or providing the alley with some mobile firefighters and doctors can be solutions to this problem.

Conclusion:

Three successful examples were discussed in this paper to show how we can maintain historical districts in spite of providing city services, producing new job opportunities for inhabitants, and attracting tourists in order to have a constant source of earning money by means of archeological tourism industry. The attention should be attributed to this point that although we must revive our cities and benefit from temporary incomes, we must keep and maintain our historical districts while providing city services, use money from tourism industry and tax of jobs that are offsprings of this industry in order to provide constant financial sources to have enough money for developing infra structures and reach sustainable urban development.

Suggestions:

1. Paying attention to the reasons of erosion and destruction of historical cities.2.paying attention to valuable city nucleus in stages of city development. 3. Benefiting from modern technology in the field of repairing. 4. Study of destroyed and old buildings in order to repair them. 5. Paying attention to topics such as architectural revival from art-architectural points to technical-constructional points. 6. Paying attention to popular and modern methods of resuscitation 7.paying attention to valuable city nucleuses in different stages of city development. 8. Paying attention to city problems such as: building public parking spaces, clinics, emergency service centers, 9. Creating logical relation between old and new districts. 10.economic support of new sections from economic facilities of old sections 11.paying attention and retaining cultural and local values of district along with development of tourism industry. 12. Giving subsidies to families who are interested in reviving and improvement 13.paying attention to development of tourism industry and creating some tourist service centers in order to provide permanent financial sources.

Acknowledgment: I am grateful to Eng. Omid Jahedpour for him help in translating and preparation this study.

Refrences:

1- International conference on civil engineering architecture and urban sustainable development (ICCAU). (2013). Baku’s “Icheri Sheher”; successful sample of conservation and restoration of historical districts , Moosazadeh, k, Fereydouni,A , Akbarlu ,A. , Tabriz.

2- Interview with Dr. A. Akbarlu, Ph.D of civil engineering, Islamic Azad University, Branch of Tabriz, 2014.

3- Interview with Dr. F. Khalili, Ph.D of History, chairman of MIRAS Social Organization, Baku, 2014

4- www.icherisheher.gov.az

© ASCE 2014

The provision of public recharging infrastructure for Electric Vehicles in North East England – is there life after subsidies?

Josey Wardle [1,3], Dr Yvonne Hübner[1], Prof Phil Blythe[1], Dr Jane Gibbon[2]

[1]Newcastle University, Transport Operations Research Group (TORG), Civil Engineering and Geosciences, Newcastle Upon Tyne, NE1 7RU, UK, email: j.wardle3@newcastle.ac.uk

[2]Newcastle University Business School, 5 Barrack Road, Newcastle upon Tyne, NE1 4SE, UK

[3]Zero Carbon Futures, SASMI, Washington Road, Sunderland, SR5 3HE, UK

1. ABSTRACT

Since 2010 over 1,100 electric vehicle (EV) charge points have been installed in North East England (NE) through the UK government subsidised Plugged in Places scheme. In parallel, over 65,000 EV journeys were studied through the Switch-EV trial. Public subsidies covering the operation of EV recharging infrastructure are now coming to an end in the region, which is likely to affect EV drivers recharging behaviour. It is however unlikely that the introduction of fees for recharging at a level which EV drivers are willing to pay will enable infrastructure owners to recoup their costs using conventional business models. Therefore making the financial case for the provision of public recharging infrastructure is still difficult. A social and environmental accounting framework may provide crucial information to enable organisations to understand the wider value provided by recharging infrastructure and its services, thereby opening up alternative business models. This paper gives an overview of the findings from these two projects and comments on the early changes observed as a result of the reduction in subsidies.

2. BACKGROUND

North East England (NE) is at the forefront of low carbon vehicle development, with Nissan manufacturing both the Nissan LEAF and Lithium-ion batteries at its Sunderland plant. Since 2010, the region has installed a comprehensive recharging infrastructure in parallel with a number of EV trials, and has become a major hub for vehicle and battery research and development, manufacturing, and training facilities throughout the EV supply chain.

The EV recharging infrastructure has been installed through Plugged in Places (PIP), a government funded programme operated by the Office for Low Emission Vehicles (OLEV) which has awarded funding to 8 areas within the UK in order to establish EV recharging infrastructure to seed the uptake of low carbon vehicles. The aims of the programme are to feedback the experience gained by creating and operating EV recharging infrastructure into future policy decisions at both regional and national

© ASCE 2014

levels. This includes the development of standards, evaluation of technologies, harmonisation of local incentives, understanding users' behaviour and its impact upon the infrastructure.

The second key element of the NE's electric vehicle activity involved 44 EVs trialled under the Technology Strategy Board's (TSB) Ultra-low carbon vehicle demonstrator (ULCVD) programme. The Switch EV trial brought together a consortium of vehicle manufacturers, data collection experts and project managers to deliver 44 new and innovative full- electric production vehicles onto NE roads.

3. METHODOLOGY

3.1 The NE PIP project.

North East England's Plugged in Places (NE PIP) project, created an integrated recharging network for EVs spanning a region of 8,600 km^2 between April 2010 and June 2013. This recharging infrastructure enables EV journeys to become feasible across neighbouring regions in the UK, Scotland and Europe. The project installed 1,138 charge points in public places, workplaces and in the homes of EV drivers across the region. The estate includes a combination of 3, 7 and 22 kW AC charge points, and the NE was the first UK area to create a regional network of 50 kW DC rapid charge points which enable EVs to be recharged to 80% in just 30 minutes. 12 rapid chargers were installed by the NE PIP project at key staging points across the region.

Potential hosts were attracted to have charge points installed on their property by various levels of grant incentives covering equipment and installation costs. Charge points have consequently been installed in locations in accordance with demand from interested hosts. In exchange for this grant funding, each host provided free electricity and free parking to EV drivers during the three year trial period, which ended in June 2013. The charge point hosts now own the NE's EV recharging infrastructure which forms the NE recharging estate. All publically accessible charge points were operated by a single network operator, Charge Your Car (CYC)[1]. CYC was funded to provide access to the entire NE recharging estate, as well as to provide customer service and charge point information via a live availability map on a dedicated website. EV drivers joined the NE PIP's CYC membership scheme at a cost of £100 per year or £10 per month, in order to receive free electricity and parking whilst recharging, access to the website to plan their journeys and their own recharging records. In addition to this public and workplace infrastructure, the project also installed over 400 domestic chargers with captive cables for EV drivers in the region to use in their own home environment.

3.2 Data Collection from charge points

CYC members were issued with their own personal radio-frequency identification (RFID) card which had a unique tag identifier attached to it, enabling them to access all makes of public and workplace EV charge points across the region. All charge points had their own unique identifying code denoting:

© ASCE 2014

- the charge point type (power delivery rating, single or double outlet),
- location type (Public = on street, in a public or commercial car park, Workplace, Rapid)
- location identification number (latitude & longitude coordinates).

All public and workplace charge point activities were then recorded by the Back Office system managing the charge point network for the project, creating a charge point management system (CPMS). For each charging activity, the tag id, the transaction start and end date and time and the energy drawn were then transmitted via the GSM network to the Back Office operating the CPMS. Both charge point hosts and EV drivers had access to their own charging data and history via a Members Portal within the CPMS.

3.3 Switch-EV trial

The Switch-EV trial ran from November 2010 until May 2013. The vehicles were fitted with data loggers that provided a range of driving and vehicle performance data, GPS and a time stamp. Selected data points were collected and analysed at Newcastle University and in parallel, driver attitudes towards driving and recharging EVs were gathered through questionnaires and focus groups. The two sets of data were then correlated to explore trends, changes in driving and recharging behaviour, general attitudes towards EVs, recharging and key issues such as cost. Most of the Switch EV drivers were also members of the CYC scheme and used the recharging infrastructure created by the NE PIP project.

Over the course of the Switch EV project, 192 participants provided answers to a pre-trial questionnaire and 101 provided answers to the post-trial questionnaire. In addition, 60 participants attended 12 focus groups; 12 individual exit interviews and 10 pre-trial interviews were conducted in order to understand drivers' attitudes towards EVs and their recharging infrastructure. Quotes from the drivers that have been reproduced from their questionnaire reposes or captured from the oral record of the focus groups are presented in quotes: "…".

3.4 Data Collection from EVs

The Switch-EV project collected hard data on the vehicles derived from the controller area network (CAN) bus of the vehicle and transmitted to a secure database through wirelessly enabled data loggers fitted within the vehicle. Those data were overlaid with GPS and time stamps derived from an additional logging unit in the vehicle. Data collected included:

- Time/date – start, end and duration of events (trips and recharging events)
- Distance travelled
- Energy used per trip
- Energy transferred per recharge
- Recharging location (home, work, public charging infrastructure)

4 RESULTS

4.1 NE PIP project – public recharging results

© ASCE 2014

The composition of the 737 public and workplace charge points in NE PIP estate is illustrated in Figure 1, broken down into three location categories – Workplace, Public and rapid chargers. Public chargers were then subdivided into On-street, Publicly owned car parks and Commercially owned car park locations for further analysis.

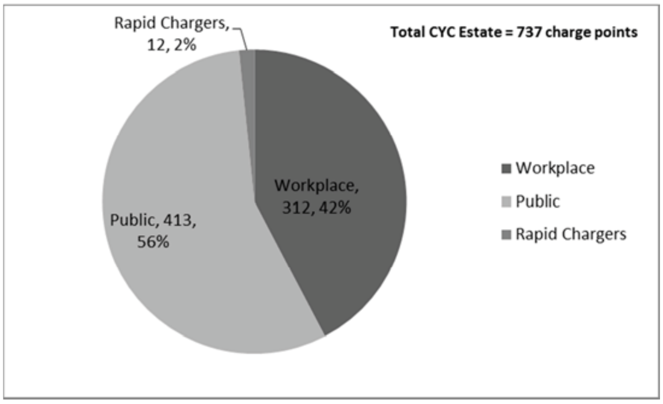


Figure 1 NE PIP Estate charge point composition by location type, June 2013.

120 hosts own the public and workplace charge points making up the NE PIP estate. However, only 17 of these hosts own more than 10 charge points each, totalling 61% of the estate. The majority (71%) of NE hosts own 2 or less charge points. The main hosts are the 12 Local Authorities in the region who together own a total of 48% of the total estate. The balance of 401 charge points consists of domestic charging units installed in the homes of EV drivers in the region.

The estate of Public, Workplace and Rapid chargers has delivered over 43,000 recharging transactions and over 311 MWh of energy to EV drivers up to the end of 2013. The proportion of transactions broken down by location category is shown in Figure 2, and the energy delivered is displayed in Figure 3.

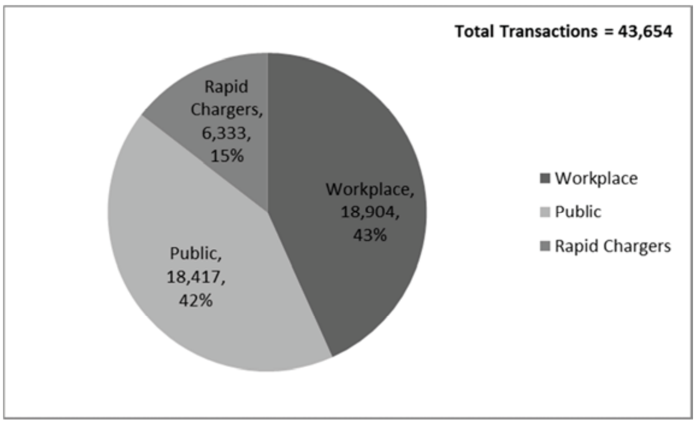


Figure 2 Recharging Transactions delivered.

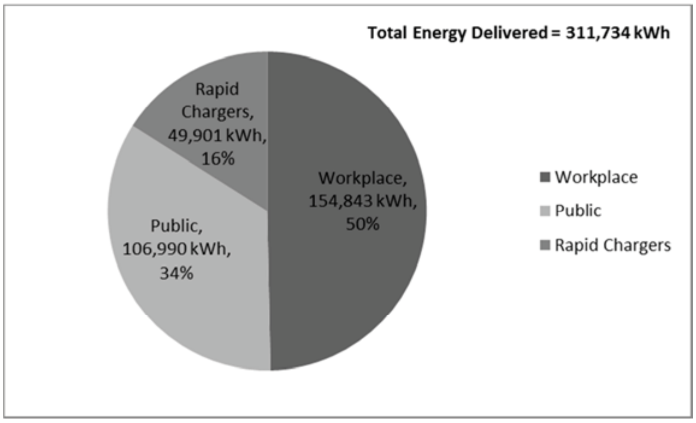


Figure 3 Energy delivered to end of 2013.

The 50 kW DC Rapid Chargers delivered a much higher proportion of the transactions (15%) and total energy provided by the estate (16%) than their composition proportion suggests (2%). Conversely, the public 3 kW and 7 kW charge points in publicly and commercially owned car parks and on streets delivered a lower proportion of the total energy (a combined 34%) compared to their composition (a combined 42%).

One of the reasons for this is the difference in usage patterns throughout the week as shown in Figure 4. Recharging events at the workplace chargers fell markedly at the weekend, similar to those of public charge points. However the number of recharging events on the rapid chargers remained relatively constant throughout the week.

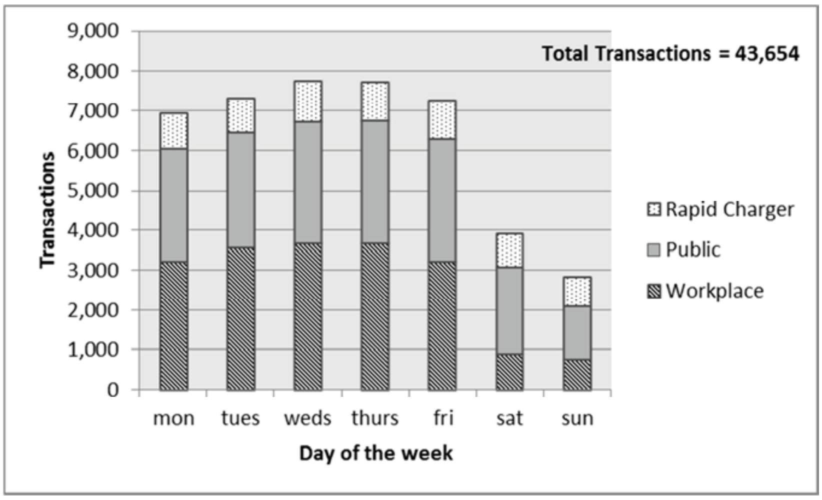


Figure 4 Number of recharging events by day of the week.

Secondly, the energy transferred per charge event differs between the different charge point location types. As shown in Table 1 below.

© ASCE 2014

Charge Point Location type	kWh
Workplace	8.19
Publicly owned carpark	5.93
Commercially owned carpark	5.91
On Street	5.10
Rapid Charger	7.88

Table 1 Average energy delivered per transaction

There has also been a large increase in the number of transactions taking place during 2013 as illustrated in Figure 5.

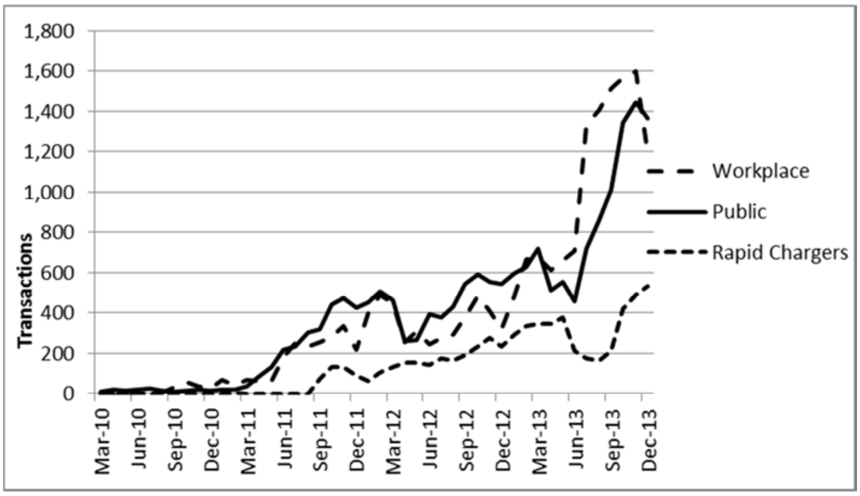


Figure 5 Growth in Transactions

This increase in recharging transactions coincides with a large increase in the number of EVs in use in NE, which rose from just over 100 in 2012 to over 450 by June 2013. These figures were collated from drivers applying for domestic chargers through the NE PIP project, rather than from UK national registration statistics which are influenced by national fleet and lease office addresses rather than EV driver addresses.

This increase also coincides with the end of the NE PIP project and therefore the end of its subsidy for charge point operation.

The changes in use of the NE's recharging infrastructure will continue to be studied over the next 3 years, alongside an analysis of how the use of Domestic chargers affects the demand for public recharging in the region.

4.2 Switch-EV – attitudes towards recharging

The Switch-EV trial saw 44 full EVs cover over 400,000 miles across the NE between March 2010 and May 2013, which account for over 90,000 journeys and over 19,000 recharging events.

Analysis of the trial data shows that 30% of charge events in the NE took place at public charge posts, primarily during peak electricity demand hours. Further analysis of the charge events revealed that nearly 20% of EV users seemed to be using the public recharging infrastructure as their primary means of recharging. In the post-trial questionnaire and focus groups, participants identified the location, common availability and free parking incentives as reasons for this behaviour.

One EV driver confirmed this in the focus groups: "*We're lucky enough to have some public infrastructure right beside where we work so that we just plug it in really while we work and then take it home … I've never charged it on anything else apart from public infrastructure so that's been the source for all our charging – or all my charging anyway.*" Another driver explained why they used public recharging infrastructure mostly to charge the vehicle: "*I've been parking [at a charge post in the city centre] which has been a godsend. My office is 25 feet away, and parking is free; so this car has actually paid us. We have saved money by renting the car*". Other drivers said that they enjoyed the convenience of parking at the EV charging bays: "*I take the EV not because I'm going to get a free parking space. It's just convenience. There are lots of them [charging posts], they're in good locations and I know I can get one and it's convenience rather than cost.*" Not surprisingly, most drivers therefore said that the access to public standard chargers and public rapid chargers was either very important or quite important.

Yet, as shown in Figure 6, respondents identified concerns about recharging as two of the key barriers to the uptake of electric EVs; the time required for recharging and availability of recharging infrastructure.

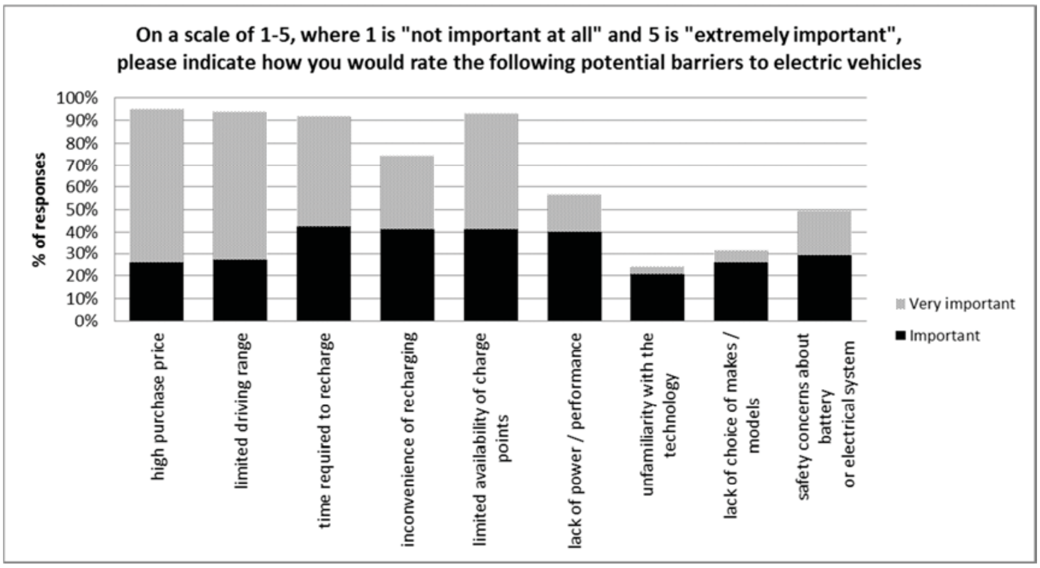


Figure 6 – Switch EV drivers perceived barriers to the uptake of EVs.

4.3 Findings from these projects

The analysis of data from these two projects shows that;

© ASCE 2014

- Almost half (48%) of the NE estate of charge points is owned by organisations with social objectives, Local Authorities.
- A relatively small proportion of NE Hosts (14%) own the majority of the NE estate (61%), so the likelihood of achieving a single business model appropriate for all is very low.
- Rapid chargers deliver a disproportionate amount of transactions and power in relation to the number of charge points within the estate
- Public 3 and 7 kW charge points deliver a lower average power per transaction than workplace based equivalents.
- During the Switch-EV trial only 30% of charging events took place on public charge points.
- The patterns of recharging behaviour observed were in part impacted by external influences, such as free parking. Therefore further analysis of EV charging behaviour is now being performed over the next 3 years whilst recharging schemes are changing in the region.

5 Subsidies for EV recharging in the UK

The early provision of EV recharging infrastructure in the UK has been heavily subsidised by UK government, local authorities and private companies as part of sustainable transport and emission reduction plans. The Plugged in Places programme is the UK's main subsidy tool to promote the provision of EV recharging infrastructure. In 2011 the UK government, through OLEV, issued its first low emission vehicle strategy entitled 'Making the Connection'[2], which set out a framework for creating a recharging infrastructure for plug-in vehicles. The Plugged-in Places programme (PIP)[3] was created to address this challenge, alongside a range of vehicle incentives. These include the Plug-in Car(PiCG)[4] and Van Grants(PiVG)[5], Plugged-in Fleets initiative[6] and Low Carbon Vehicle Public Procurement programme(LCVPP)[7], which are all designed to encourage the up-take of low-carbon vehicles in the UK.

With the end of the funded operation of the NE charge points by the NE PIP project, the public charge point estate must now become self-sustaining. Charge point owners can now therefore charge EV drivers a fee for the use of their EV charging facilities, as a way of recouping their up-front capital investment and on-going operating costs.

Since the NE PIP project no longer pays for the operation of the NE's recharging estate, charge point owners must engage a Network Operator to provide the necessary charge point management services (access, administration of fees, customer service, fault reporting etc). Many, but not all, of the charge points installed through the NE PIP project are now operated by CYC on a commercial basis. However, few of the owners of these charge points have yet chosen to charge a fee to EV drivers. Therefore, most NE charge point owners are continuing to provide a subsidy to EV drivers, as a way of attracting EV drivers to their facilities, whether employees or members of the public, in line with their sustainable transport plans.

© ASCE 2014

Other associated financial incentives have also continued in the region, such as the offer of free parking. All 12 Local Authorities in NE now provide public charge points as a result of the NE PIP project, and in some cases they have incurred large losses in parking revenue as a result. Increasing financial pressures have also been placed on Local Authorities by UK government and how this will affect social provision such as recharging infrastructure is yet to be established.

Workplace hosts are also likely to retain the free electricity offer for their employees as long as the relevant tax incentives are maintained and demand does not result in excessive electricity costs. However, this situation is likely to change in the future if the UK Government's approach to employee benefits in kind changes or if demand by EV drivers makes electricity costs a problem to employers.

6 Business Models for EV recharging in public locations

Currently there is no feasible, purely economic business model for the provision of public recharging infrastructure in the NE.

The current demand for public recharging transactions from EV drivers is not high enough to fully cover the economic costs of capital, installation, operation and maintenance. The actual uptake of EVs and therefore demand for recharging transactions has been lower than the predictions made in 2010, affecting the early business models envisaged for on-going operation and increasing provision. The consequence is that NE charge point owners are continuing to financially support the costs of operation of recharging infrastructure and cannot yet foresee an acceptable conventional business model.

6.1 The charge point owner's perspective

The charge point owner is now at the centre of a system of infrastructure which is seen as essential by many stakeholders such as government, environmental bodies and EV drivers, and they are expected to at least maintain the current level of supply. However, the expectations and assumptions upon which NE hosts made the decision to adopt charge points, have not materialised.

NE charge point owners are a diverse group of organisations who have decided to provide recharging infrastructure for a variety of political, economic, social and environmental reasons. Peer pressure is also a relevant factor in the region because of the high profile role the NE has played in low carbon vehicle development to date.

The Climate Change Act[8] is driving the implementation of sustainable transport solutions in the UK in order to reduce domestic greenhouse gas emissions. Local Authorities (LA) are therefore being encouraged by political motivations to provide appropriate services, such as EV recharging infrastructure. This represents a model of provision for social good, as opposed to the likely economic motivations of a private business. LAs may have three target audiences in which the provision of recharging infrastructure should encourage low carbon vehicle uptake; the general

© ASCE 2014

public, its own employees, and its own fleet. Private Businesses on the other hand would be targeting only their employees and own fleets. There is also a third category of NE host such as Universities which have some social and environmental targets leading them to offer recharging services to visitors as well as employees, but not to the general public.

However, the customers wishing to use these services, EV drivers, may have very different demands to those assumed by the charge point hosts.

6.2 The EV driver's perspective

EV drivers' demands for public recharging infrastructure are based on cost, ease of use and location. The additional services provided such as free parking have been a key determinant in NE charge point usage to date. The available capacity and reliability of charge points will also become increasingly important as EV volumes increase and in certain locations with dense EV populations this has already become a problem. An increased provision of rapid charge points would help resolve this problem but this incurs high up-front costs and higher electricity costs as it encourages greater use.

6.3 The role of subsidies

The NE's early-to-market EV recharging estate was created and operated under public subsidy, in order to seed the marketplace for further EV and recharging equipment adoption. The availability of NE PIP grant funding towards purchase and installation costs heavily influenced hosts decisions to adopt charge points. These grants have now ended so one hypothesis is that provision will not increase further without new government subsidies being introduced. The NE PIP project also paid all system operating costs until June 2013, so charge point owners were therefore shielded from the true costs of operation. The result is that NE charge point owners have adopted recharging infrastructure without being fully aware of the costs of operation.

As public subsidies decline, the infrastructure owners must find other ways to cover the on-going costs of operation and to recover the capital investments made, in order to provide a continuing service to EV drivers.

6.4 The role of fees for EV recharging

As charge point owners are increasingly exposed to real operating costs they will also become aware of the new commercial opportunities available to them, such as fees, marketing and the provision of associated services. The introduction of fees for EV recharging is likely to affect the behaviour of EV drivers in terms of their recharging habits (time, location, duration etc.), willingness to pay, journey characteristics and potentially their overall EV usage. These behavioural changes will, in turn, affect the owners of recharging equipment and the businesses operating this equipment in recharging networks (Network Operators).

Increased understanding of the operating costs is likely to drive assessments concerning fees and further recharging provision in different directions to those taken

© ASCE 2014

against the backdrop of public subsidy. Type, quantity and location of recharging equipment are all key determinants in this business model. Therefore studies of comparative usage data from different types of recharging equipment and charge point location types should be used to inform future fee structures.

6.5 The way forward – a broader measurement model ?

NE charge point owners are now faced with five elements influencing the business model for operating their recharging infrastructure; Charge point features, EV features, EV drivers' requirements, charge point technology and recharging technology. Each of these areas contains unknown factors and therefore requires predictions based on market intelligence to date. Many charge point owners do not have the capacity or business need to carry out this in depth work.

NE charge point owners also have varying reasons for providing recharging infrastructure, including political, social and environmental objectives many of which cannot be measured in purely economic terms.

There is therefore the potential for a social and environmental accounting model to be developed which will provide an alternative accounting framework for the provision of public recharging infrastructure. A social account with a measure of social return on investment would enable an organisation to assess and report its impact on society and the environment, alongside its economic measures. A flexible framework could be used to collect, analyse and interpret quantitative and qualitative data resulting from the provision of recharging infrastructure. Use of such a framework would enable charge point owners to understand and evaluate the wider value provided by recharging infrastructure and its services, and to value how it affects the people, environment and resources they are responsible for. Follow-on work will be carried out by the authors to build and assess such a framework. An analysis of charge point owners' attitudes towards their recharging infrastructure will be performed, in parallel with the authors' continuing longitudinal study of the usage of NE charge points.

7 CONCLUSIONS

The provision of EV recharging infrastructure in the NE and the UK is important to both government and EV drivers. Therefore either a sustainable business model is required to enable charge point owners to continue provision, or subsidies must continue. A sustainable business model is likely to have to contain social, environmental and economic elements, for which an alternative method of accounting such as a social and environmental framework may be suited.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the funding support of the UK's Engineering & Physical Sciences Research Council and the Economic & Social Research Council

© ASCE 2014

funding of iBUILD (Infrastructure BUsiness models, valuation and Innovation for Local Delivery) - EP/K012398/1. (http://research.ncl.ac.uk/ibuild/)

REFERENCES

1. *Charge Your Car Limited*. Available from: http://chargeyourcar.org.uk.
2. Office for Low Emmission Vehicles, *Making The Connection, the Plug-in Vehicle Infrastructure Strategy*, OLEV, Editor June 2011: London.
3. Office for Low Emission Vehicles. *Plugged in Places*. 2010; Available from: https://www.gov.uk/government/publications/plugged-in-places.
4. Office for Low Emission Vehicles, *Plug-in Car Grant*, 2011: https://www.gov.uk/government/publications/plug-in-car-grant.
5. Office for Low Emission Vehicles, *Plug-in Van Grant*, 2012: https://www.gov.uk/government/publications/plug-in-van-grant.
6. Energy Savings Trust. *Plugged in Fleets Inititative*. 2013; Available from: http://www.energysavingtrust.org.uk/Organisations/Transport/Products-and-services/Fleet-advice/Plugged-in-Fleets-Initiative-100.
7. Office for Low Emission Vehicles. *Low Carbon Vehicle Public Procurement* 2011; Available from: https://www.gov.uk/government/publications/the-low-carbon-vehicle-public-procurement-programme-support-for-low-carbon-vans.
8. Department of Energy and Climate Change, *Climate Change Act 2008*, DECC, Editor: http://www.legislation.gov.uk/ukpga/2008/27/pdfs/ukpga_20080027_en.pdf.

Project Selection Regarding Life-Cycle Oriented and Equity-Intensive Projects: A Critical Assessment of the PPP Project Selection Process in the Construction Industry

S. Weissenböck[1] and G. Girmscheid[2]

[1] Scientific Assistant and Doctoral Student, Institute of Construction and Infrastructure Management, ETH Zurich, Stefano-Franscini-Platz 5, IBI, HIL F 22.2, 8093 Zurich, Switzerland; PH (+41) 44 633 6783; FAX (+41) 44 633 1452; email: weissenboeck@ibi.baug.ethz.ch
[2] Chair of Construction Process and Enterprise Management, Institute of Construction and Infrastructure Management, ETH Zurich, Stefano-Franscini-Platz 5, IBI, HIL F 23.3, 8093 Zurich, Switzerland; PH (+41) 44 633 3114; FAX (+41) 44 633 1452; email: girmscheid@ibi.baug.ethz.ch

ABSTRACT

At first glance, project selection decision-making in construction companies dealing with life-cycle oriented and equity-intensive projects is dominated by intuition rather than structured quantitative processes. In contrast, companies from other business fields (e. g. institutional investors) that are also dealing with these projects are successfully using quantitative instruments to support their project selection processes.

The objectives of this paper are to analyze if the assumption that intuition guides project selection processes in construction companies can be justified, and to investigate how this process can be enhanced. To meet these objectives, three main aspects are discussed. First, the state of practice in the construction industry is outlined by showing a practical example of a project selection process that is currently being applied by an international construction company. Second, the practically applied project selection process is assessed critically and improvement potentials are outlined. Finally, the concept of a quantitative project selection model for life-cycle oriented projects in the construction industry is presented.

This paper represents one of the first steps of a research project that aims to develop a quantitative project selection model, which will enable construction companies to select projects suitable to their specific profile.

INTRODUCTION

Project selection processes are generally predetermined by the superordinate strategy of an enterprise. This enterprise strategy defines, for example, business areas of interest for the company, key markets and competitive strategies (Girmscheid 2010a). Nevertheless, every specific business unit (BU) has to decide or at least suggest, which specific projects they would like to apply for. Consequently, the

© ASCE 2014

enterprise as a whole or the particular BU's themselves have to define a project selection process, which supports them in identifying the most suitable projects.

Defining an appropriate project selection process is crucial for the success of every BU, and for the success of a construction company as a whole (Girmscheid 2010c). Nevertheless, it is most important for BU's dealing with life-cycle oriented and equity-intensive projects e. g. Public Private Partnership (PPP) projects. PPP's represent the most established type of life-cycle oriented and equity-intensive projects and have therefore been focused on within this paper. PPP projects as well as life-cycle oriented and equity-intensive projects in general are characterized by enormous bid costs, high equity investments and long contract durations (Weissenböck und Girmscheid 2013).

To get a better understanding about the project selection processes in regard to life-cycle oriented and equity-intensive projects and specifically PPP, this paper analyzes the state of practice by using a practical insight out of the construction industry. Subsequently, the analyzed PPP project selection process is assessed critically and potentials for improvement are outlined. Finally, the concept of a quantitative project selection model for PPP projects in the construction industry will be introduced briefly.

STATE OF PRACTICE – PPP PROJECT SELECTION IN THE CONSTRUCTION INDUSTRY

The actual project selection process in the construction industry was investigated by reviewing the current process of a large, international construction company that is successfully completing PPP projects in various countries and fields (e. g. social infrastructure, highways, tunnels). Due to confidentiality reasons the company cannot be named, nor can the underlying publications be cited.

The examined PPP project selection process is divided into two phases (Figure 1). Phase 1 deals with the selection of potential target countries/target markets. Phase 2 deals with the selection of specific projects within the identified target countries/target markets.

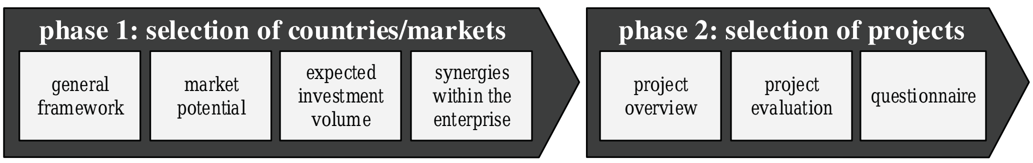


Figure 1. Project selection in the construction industry – State of practice.

Phase 1: Selection of target countries/target markets

In this phase, potential target countries and potential target markets are analyzed. Due to the fact that the analysis of every target country/target market involves time, effort and costs, a pre-selection based on the enterprise strategy as well as on subjective evaluations of the responsible decision-makers has been conducted. After this pre-selection, a certain number of potential target countries or potential target markets are analyzed in further detail.

© ASCE 2014

The criteria used for analyzing the target countries/markets can be divided into two main groups:

1) the general framework (economic/legal/social) within the country/market and
2) the specific market potential.

In addition to these two groups, a qualitative evaluation regarding the expected investment volume (short-, medium- and long-term) is conducted and the potentials of possible synergies within the enterprise are estimated (Figure 1).

- General framework (economic/legal/social)

Within the group of the general framework regarding the economic, legal, and social environment, the criteria listed below are evaluated:

- budget balance (*),
- GDP (*),
- demographic development (*),
- legal framework,
- financial market (*),
- country rating (*),
- potential partners and
- cultural fit.

The criteria marked with an asterisk (*) represent “hard facts”. For these “hard” criteria, key figures, ratings or grades are available and can be used within the evaluation process. Although quantitative data are available, every criteria has been translated into a qualitative ranking scale (grades 0 to 5) (Table 2).

The unmarked criteria represent “soft” criteria. These criteria have been evaluated by using the questionnaire and rating system shown in Table 1.

Table 1. Description of “soft” criteria regarding the general framework.

general framework: description of "soft" criteria	
legal framework	Do PPP laws exist that disburden PPP processes? (0 = no laws; 5 = laws exist and they proved as practical)
potential partners	What are the chances to find potential construction and joint venture partners? (0 = very poor; 5 = very good)
cultural fit	How is the work and social environment compared to the domestic market? (0 = very different; 5 = similar to the domestic market)

Evaluating every “hard” and “soft” criterion out of this group for every single potential target country or target market leads to results as shown, for instance, in the example in Table 2. “Soft” criteria are highlighted by using the grey background color.

© ASCE 2014

Table 2. Example for the evaluation of the general framework.

Criterion		Country 1	Country 2	Country 3	Country 4	Country 5	Country 6	Country 7	Country 8	Country 9	Country 10
general framework (economic / legal / social)	budget balance	3	1	2	2	3	4	3	3	3	2
	GDP	2	2	2	4	4	4	3	3	2	3
	demographic development	2	2	3	3	3	4	5	5	2	3
	legal framework	2	1	0	0	0	0	0	1	3	0
	financial market	2	3	1	2	1	4	2	4	3	4
	country rating	2	3	1	2	1	4	2	4	3	3
	potential partners	5	5	3	2	2	3	2	3	4	2
	cultural fit	3	2	1	3	1	3	3	4	3	2

- Market potential

The market potential is analyzed considering the fact that entering a new country/market is commonly associated with considerable costs. These costs have to be justified by a corresponding volume of projects in potential target countries/markets. Girmscheid (2010a) estimates that the costs caused by a strategy that aims for the development of a new market are four times higher than the costs caused by a strategy that aims for a higher penetration of existing markets.

Within the market potential group, the criteria listed below are evaluated:

- former market volume,
- expected project pipeline (short- to medium-term),
- potential for further projects (medium- to long-term),
- competition,
- profit opportunities,
- market entry barriers and
- size of expected projects.

All criteria within the market potential group have been treated as “soft” criteria, i. e. without evaluating quantitative data. As a consequence, the evaluation of all criteria within the market potential group has been conducted by using the questionnaire and rating system shown in Table 3.

© ASCE 2014

Table 3. Description of "soft" criteria regarding the market potential.

market potential: description of "soft" criteria	
former market volume	How good is the PPP experience in the country (number of projects)? (0 = not any; 5 = many)
expected project pipeline (short- to medium-term)	How many projects can be expected short- to medium-term? (0 = not any; 5 =many)
potential for further projects (medium- to long-term)	Is there further medium- to long-term potential for PPP projects apart from the expected pipeline? (0 = no, not at all; 5 = yes, there is great potential for further PPP projects)
competition	How strong is competition in the market? (0 = very high - little chances to win a project; 5 = no competition at all)
profit opportunities	What are the chances to achieve returns in this market? (0 = very poor chances of achieving returns; 5 = very good chances of achieving returns)
market entry barriers	How strong are market entry barriers? (0 = very high, no chances to enter the market; 5 = no barriers, easy to enter the market)
size of expected projects	What's the expected size (investment volume) of the expected projects? (0 = too small for our company; 5 = perfect for our company)

Evaluating every criterion within this group for every single potential target country or target market leads for instance to results such as those shown in the example in Table 4.

Table 4. Example for the evaluation of the market potential.

	Criterion	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6	Country 7	Country 8	Country 9	Country 10
market potential	former market volume	0	2	0	0	0	2	1	1	0	2
	expected project pipeline (short- to medium-term)	0	0	0	0	0	2	2	3	2	2
	potential for further projects (medium- to long-term)	4	1	2	2	2	2	5	4	2	3
	competition	3	2	4	4	4	2	3	2	3	3
	profit opportunities	4	3	3	3	3	2	2	3	4	3
	market entry barriers	2	4	3	3	3	3	3	4	3	3
	size of expected projects	2	3	2	2	2	4	3	4	4	2

© ASCE 2014

- Expected investment volume (short-, medium- and long-term)

The results of evaluating the general framework (axis of abscissae) and the market potential (axis of ordinates) are graphically displayed in Figure 2. Furthermore, a third dimension is displayed for every target country/target market, which is represented by the size of the respective bubble.

This third dimension represents the expected future PPP investment volume (short-, medium- and long-term) and is calculated by summing up the evaluation of two criteria from the market potential group: (1) the expected project pipeline (short- to medium-term) and (2) the potential for further projects (medium- to long-term).

- Synergies within the enterprise

In addition to the criteria mentioned above, the analyzed construction company evaluates if synergies within the enterprise can be utilized by starting a PPP project in a target country/target market. Life-cycle oriented projects as PPP projects are particularly suited to utilize synergy potentials within the enterprise and offer opportunities to extend the value chain (Girmscheid 2010b). Both the utilization of synergy potentials and the extension of the value chain represent core elements of the corporate strategy in big construction enterprises (Bilfinger SE 2014, HOCHTIEF Aktiengesellschaft 2014, STRABAG SE 2012) and consequently, are screened before selecting new PPP projects.

The criterion of synergies within the company, therefore rather represents an exclusion criterion than an evaluation criterion.

- Results of phase 1: Selection of target countries or target markets

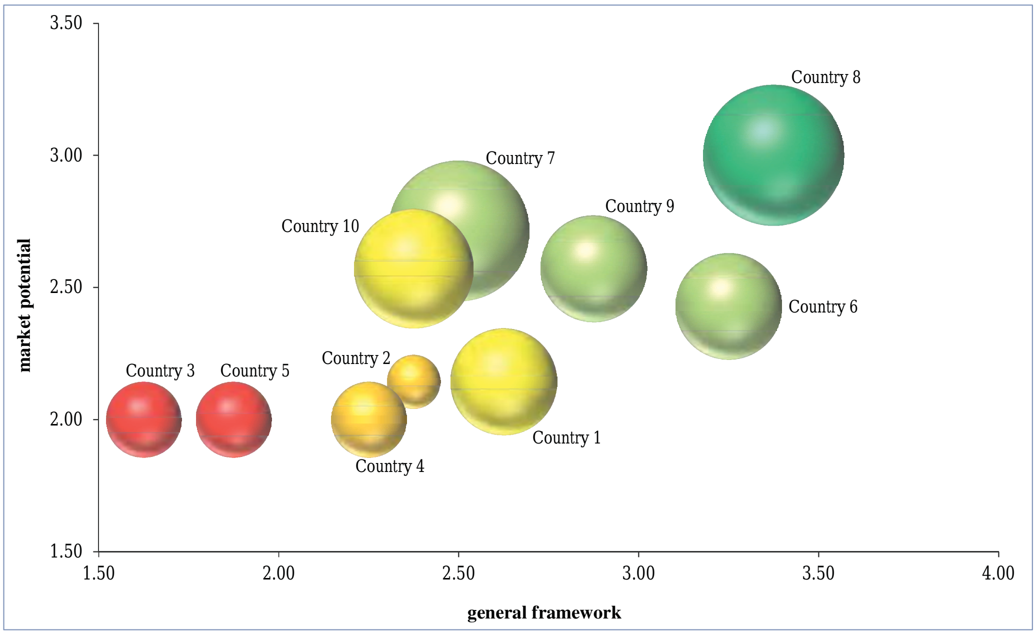


Figure 2. Valuation results regarding the selection of target countries and target markets.

© ASCE 2014

Figure 2 illustrates the results of the evaluation process. The values on the axis of abscissae represent the arithmetic mean of the equally weighted criteria of the general framework. The values on the axis of ordinates represent the arithmetic mean of the equally weighted criteria of the market potential. The size of the bubbles represents the expected PPP investment volume. The evaluation of synergies within the enterprise is not displayed in Figure 2 due to the reason mention above (no evaluation criterion).

Phase 2: Selection of specific PPP projects

After completing the selection of potential target countries and target markets, the evaluation and selection of particular PPP projects in the identified target countries/target markets is conducted. The objective of this step is to arrive at a "shortlist" of PPP projects, for which the tendering process should be started.

In order to standardize the evaluation process for all departments and disciplines dealing with PPP projects, a form sheet was developed which has to be completed for every potential PPP project. This form sheet is transmitted to the responsible decision-makers, who decide whether or not to commence with a respective PPP project and the necessary support processes (forming a consortia, etc.).

The standardized form for evaluating potential PPP projects consists of the following three parts:

1) a project summary,
2) an actual project evaluation and
3) a questionnaire.

The three areas of concern are examined subsequently in a few sentences.

- Project summary

The purpose of the project summary is, as the name indicates, giving the responsible decision-makers a brief overview of the key facts of a PPP project.

The project summary of the investigated enterprise contains the following aspects: name of the particular PPP project, country and location, the responsible BU within the company, the type of project including a rough specification (e. g. "highway, traffic volume risk, brown-field" or "highway, availability payments, green-field"), the estimated capital expenditure, the estimated volume of the construction activities, the estimated volume of the operating and maintenance services, the estimated equity requirements, the targeted share of the equity, the expected duration of the contract, the expected date of commencement of construction and the expected date of completion.

- Project evaluation

The respective PPP project is evaluated solely on a qualitative basis. The evaluation includes specifications on the following aspects: advantages of the PPP project, disadvantages of the PPP project, opportunities arising from the PPP project, threats arising from the PPP project, already known obstacles that could lead to a withdrawal from the tender process as well as the next steps planned within the project.

© ASCE 2014

The first four aspects mentioned are, in particular, very general and leave much room for interpretation.

- Questionnaire

The third and last part of phase 2 (selection of specific PPP projects) consists of a predetermined list of questions. All questions are closed questions and the respective answers can be justified by brief comments. The questions are divided into five areas of concern. These are: (1) the legal framework, (2) the project environment, (3) the profitability of the PPP project, (4) the bankability of the PPP project sustainability and (5) the suitability with the corporate strategy.

As one can imagine, many questions asked here deal with facts that have already been evaluated in phase 1, the selection of potential target countries/target markets.

The actual decision process is executed by the responsible decision-makers. Their decision is based on and justified through the described evaluations and forms of phase 1 and 2 (see above).

CRITICAL ASSESSMENT OF THE PPP PROJECT SELECTION PROCESS

The PPP project selection process that is currently applied in practice in the construction industry shows many commonalities with the project selection process suggested by Girmscheid (2010c) for ordinary construction projects. A further development of the project selection process, which considers the extended remit of PPP projects, is currently hardly taken into consideration. Construction companies emphasize that a more substantiated PPP project selection process is difficult to apply due to a small level of knowledge about a specific project at call for tender stage. This argument is definitely valid. Nevertheless, the current project selection process gives room for improvement. The following three aspects, in particular, are criticized:

1) Quantitative and proven data has been transferred into a qualitative ranking scale.
2) All criteria have been equally weighted. It should be distinguished between more and less important criteria.
3) Many criteria have been evaluated twice. Once by evaluating potential target countries/target markets, once within the questionnaire. A structured project selection process should evaluate all important criteria just once.

Comparing the current PPP project selection process of the construction industry with the processes that are applied in comparable business areas indicates important further enhancement potentials: the consideration of both the current project portfolio and diversification effects.

Institutional investors, for instance, make use of equity investments in PPP projects due to their positive diversification effects on the portfolio as a whole and their low correlation to other investments (Peng and Newell 2007; Weber and Alfen 2010). These investors are selecting new equity investments by considering the effects, which a new project might have on the current portfolio and successfully

© ASCE 2014

apply quantitative instruments as Modern Portfolio Theory (MPT). Recent publications show that even a portfolio consisting solely out of infrastructure projects in various regions and sectors offers great potential for diversification and risk minimization (Bahçeci and Weisdorf 2014). Obviously, there is a certain potential of diversification that could be utilized by construction companies dealing with life-cycle oriented and equity-intensive projects as well.

The real estate business takes portfolio considerations into account as well. Wellner (2011) verified that MPT can be applied for real estate investment decisions. These investments are highly comparable to PPP project investments. Viezer (2010) goes even further and supposes that private equity investors (e. g. construction companies dealing with PPP projects) "…may someday find MPT as a useful engine of inquiry" (p. 753).

These recent findings encouraged the authors of this paper to investigate the potential of MPT in regard to PPP project selection. Consequently, a research project has been launched to develop a new PPP project selection model (PPP-PS-model).

CONCEPTION OF THE PPP-PS-MODEL

Considering the aspects that have been criticized most after investigating the current PPP project selection process, the new PPP-PS-model has to reflect the following aspects:

- the new model has to be developed on a quantitative basis,
- the criteria have to be weighed according to their importance,
- all criteria should occur just once,
- the problem of limited knowledge about PPP projects at call for tender stage has to be taken into account and
- the current PPP project portfolio as well as diversification effects have to be considered.

Based on these objectives, the authors started developing a new PPP-PS-model. The basic conception of this model has been introduced by Weissenböck and Girmscheid (2013) and is displayed in Figure 3.

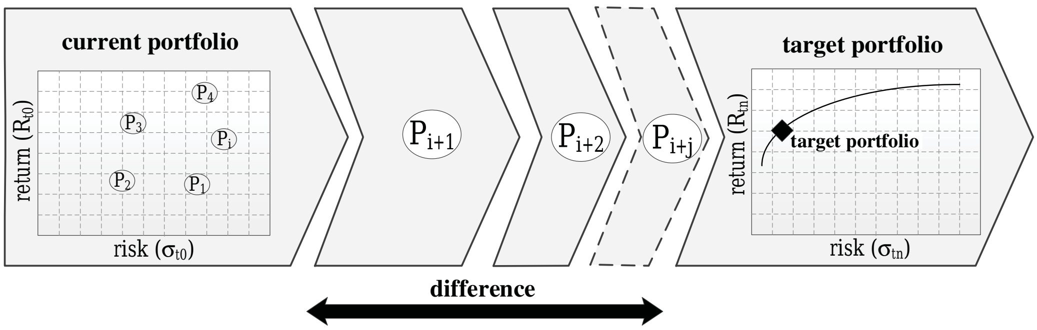


Figure 3. Conception of the PPP-PS-model (after Weissenböck and Girmscheid 2013).

© ASCE 2014

As demonstrated in Figure 3, the new PPP-PS-model involves three modules:

1) the analysis of the current portfolio,
2) the evaluation of the target portfolio and
3) the determination of an optimal new project.

Additional information regarding the conception of the model has been presented by Weissenböck and Girmscheid (2013).

CONCLUSION

This paper focused on the investigation of the current project selection process in the construction industry regarding life-cycle oriented and equity-intensive projects e. g. PPP projects. Thankfully, the authors got access to various documents of a construction company that is successfully dealing with PPP projects in various countries and fields (e. g. social infrastructure, highways, tunnels).

The investigations confirmed that project selection decision-making in construction companies dealing with life-cycle oriented and equity-intensive projects is dominated by intuition rather than structured quantitative processes. Qualitative rankings have predominantly been used, all criteria have been equally weighted and many criteria have been evaluated twice. Hence, there is room for improvement in the PPP project selection process of construction companies.

In addition, the comparison with other business areas showed that quantitative instruments such as MPT are commonly used and that diversification effects as well as the current portfolio are considered regularly.

Therefore, the authors initiated a research project, which aims to develop a new quantitative project selection model. Applying this model will enable construction companies to select projects suitable to their specific profile and will support them in minimizing their risks. Consequently, this might lead to an increasing number of both successful life-cycle oriented projects and successful construction companies within this field. Both offers the potential of an increasing economic sustainability of construction companies.

REFERENCES

Bahçeci, S., and Weisdorf, M. (2014). “The Investment Characteristics of OECD Infrastructure: A Cash-Flow Analysis.” Rotman International Journal of Pension Management, 7 (1): 32–39.

Bilfinger SE (2014). “Strategy - Strategic program "BEST" - Bilfinger Escalates Strength.” Bilfinger SE, http://www.bilfinger.com/unternehmen/strategie/>(Feb. 5, 2014).

Girmscheid, G. (2010a) Strategisches Bauunternehmensmanagement - Prozessorientiertes integriertes Management für Unternehmen in der Bauwirtschaft, Springer, Heidelberg.

© ASCE 2014

Girmscheid, G. (2010b) Projektabwicklung in der Bauwirtschaft - Wege zur Win-Win-Situation für Auftraggeber und Auftragnehmer, Springer, Berlin.

Girmscheid, G. (2010c) Angebots- und Ausführungsmanagement - Leitfaden für Bauunternehmen Erfolgsorientierte Unternehmensführung vom Angebot bis zur Ausführung, Springer, Berlin.

Hochtief Aktiengesellschaft (2014). "Strategy - Toward the future. With solutions from HOCHTIEF." HOCHTIEF Aktiengesellschaft, http://www.hochtief.com/hochtief_en/680.jhtml>(Mar. 6, 2014).

Peng, H. W., and Newell G. (2007). "The Significance of Infrastructure in Investment Portfolios." Pacific RIM Real Estate Society Conference, Fremantle, Australia.

Strabag SE (2012). "STRATEGY - Building Visions. Building Values. Building Europe." STRABAG SE, http://www.strabag.com/databases/internet/_public/content.nsf/web/EN-STRABAG.COM-strategie_strabag.html#?men1=1&sid=120&h=2> (Mar. 6, 2014).

Viezer, T. W. (2010). "The Application of Modern Portfolio Theory to Real Estate: A Brief Survey." Handbook of Portfolio Construction: Contemporary Applications of Markowitz Technique, Springer, New York.

Weber, B., and Alfen, H. W. (2010) Infrastructure as an Asset Class - Investment Strategies, Project Finance and PPP, John Wiley & Sons, Chippenham.

Weissenböck, S., and Girmscheid, G. (2013). "Concept of a quantitative project selection model for PPP projects." CIB World Building Congress 2013 - Construction and Society, CIB, Brisbane, Australia.

Wellner, K. (2011). "Transforming Markowitz portfolio theory into a realistic real estate portfolio allocation process." Annual Conference of the European Real Estate Society, Eindhoven, Netherlands.

© ASCE 2014

A Blueprint for Healthy Communities – Case study of Mueller Community and Colony Park project in Austin, Texas

Hessam Sadatsafavi [1], Autumn Leveridge [2], Matt McCreary[3], Jeffrey Slater[4], Travis Wit[5], Chia – Yuan Yu [6], Dan Zhao[7], Xuemei Zhu[8]

[1] Texas A&M University, Zachry Department of Civil Engineering, CE/TTI 710, 3136 TAMU, College Station, TX 77843-3136, email: hessam@neo.tamu.edu

[2] Texas A&M University, Zachry Department of Civil Engineering, CE/TTI 710, 3136 TAMU, College Station, TX 77843-3136, email:autumn.leveridge@gmail.com

[3] Texas A&M University, College of Architecture, Teague 129G, 3137 TAMU, College Station, TX 77843-3137, email: mmccre1@neo.tamu.edu

[4] Texas A&M University, College of Architecture, Teague 129G, 3137 TAMU, College Station, TX 77843-3137, email: sklater@neo.tamu.edu,

[5] Texas A&M University, College of Architecture, Teague 129G, 3137 TAMU, College Station, TX 77843-3137, email: tw1147@neo.tamu.edu

[6] Texas A&M University, College of Architecture, Teague 129G, 3137 TAMU, College Station, TX 77843-3137, email: yu17891@neo.tamu.edu

[7] Texas A&M University, College of Architecture, Teague 129G, 3137 TAMU, College Station, TX 77843-3137, email: zhaodan1205@neo.tamu.edu

[8] Texas A&M University, College of Architecture, Teague 129G, 3137 TAMU, College Station, TX 77843-3137, email: xuemeizhu@neo.tamu.edu

ABSTRACT

Urban sprawl has become a very common development pattern in the United States, despite historical precedent that compact, mixed-use development offers a variety of uses and activities beneficial to users. One example of compact, mixed-use development is the Mueller Airport redevelopment project in Austin, Texas. A multidisciplinary group of seven graduate students from Texas A&M University College of Architecture and the Department of Civil Engineering conducted a study to create design guidelines for the Colony Park master plan, another compact, mixed-use community in Austin. Phase I attempted to determine and measure the site components found within the Mueller neighborhood that promote, or hinder an active living lifestyle. Phase II of the project reviewed the information and data acquired in Phase I and applied the results to create design guidelines. Focusing on the health aspects, the team created four groups of guidelines regarding land development patterns; parks, greenways, and open spaces; street systems; and building and urban design.

INTRODUCTION AND BACKGROUND

Urban sprawl has become a very common development pattern in the United States, despite historical precedent that compact, mixed-use development offers a variety of uses and activities beneficial to users (Duany et al. 2010). The Sierra Club (1998) defines urban sprawl as "low-density development beyond the edge of service and employment, which separates where people live from where they shop, work,

© ASCE 2014

recreate and educate, thus requiring cars to move between zones" and Ewing (1997) states sprawl is a combination of three things: "1) leapfrog or scattered development; 2) commercial strip development; and 3) large expanses of low density or single-use developments, as well as by such indicators as low accessibility and lack of functional open space."

Sprawl has created several problems such as reduced water quality (McKenzie et al. 2009), increased storm water runoff (Smith and Perdek 2004), reduced wildlife (Heimlich and Anderson 2001), increased heat-island effect and energy usage (Gartland 2008), increased child and adult obesity rates and reduced quality of life and health (Frumkin et al. 2004), and increased traffic quantity (Stone 2008). The sprawling U.S. land development patterns have also limited or eliminated an active living lifestyle (i.e., being physically active during daily routines, such as walking to school) (Duany et al. 2010)

Despite the current sprawl development pattern, compact, mixed-use land development patterns can be applied, if allowed, to create usable and sustainable cities that offer users an active living lifestyle. Some states have curbed urban growth patterns using a method called 'smart growth' (Johnson 2001). Smart growth incorporates mixed-use designs, with transit access, as well as focusing on housing diversity, traffic congestion and limiting environmental degradation (Johnson, 2001). In addition, as reported by the U.S. Department of Housing and Urban Development (USHUD), voters in many areas have attempted to limit suburban areas and preserve and or increase green space (USHUD, 1999). Elkin et al. (1991) defined compact development as "a form and scale appropriate to walking, cycling and efficient public transport and with a compactness that encourages social interaction." When combined with diverse activities, such as retail and local industry, a mixture of social and private housing and a mixture of housing types, the land development pattern is considered compact, mixed-use (Grant 2002).

One example of compact, mixed-use development is the Mueller Airport redevelopment project in Austin, Texas. The development is a certified by the U.S. Green Building Council's Leadership in Energy & Environmental Design for Neighborhood Development (LEED ND) program. The project was developed on the former site of Austin's airport, which was closed in 1999. Construction on the 711-acre site began in 2007 and is expected to take ten years or more for completion. Once complete, the site is estimated to hold 650,000 sq. ft. of retail, 4,600 homes, and 140 acres of open space. The project will house an estimated 10,000 residents and while the site's business sector will employ 10,000 people. Much of the area offers residents several activities and is connected with sidewalks and various transportation options are available or will be available as the site develops. The design team created a town center in the plan with the hopes it would be the focal point for the community. Six components were described by the design team for the importance of the town center: Identity, Connectivity, Walkability, Convenience, Diversity, and Authenticity.

The city of Austin is engaged in creating another sustainable community on 208-acres of publicly owned land in Colony Park. The Colony Park Sustainable Community Initiative is a 3-year Community Planning Process and will incorporate

© ASCE 2014

best practice strategies to create a model sustainable and livable mixed-use, mixed-income community. At the time of this study in spring 2013, the city of Austin was requesting qualifications from architects, engineers, landscape architects and or urban planning firms to create a master plan for the development of the property. The goals of the project are to create a livable mixed-use/mixed-income community that incorporates strategies for energy-efficient building design, water conservation and zero waste. The area has received funding from the U.S. Department of Housing and Urban Development and has been rezoned as Planned Unit Development (PUD). The proposed Colony Park community supports the U.S. Department of Housing and Urban Development's six "Livability Principles," as follows:

- Provide more transportation choices
- Promote equitable, affordable housing
- Enhance economic competitiveness
- Support existing communities
- Coordinate policies and leverage investment
- Value communities and neighborhoods

STUDY OBJECTIVES AND METHODS

A multidisciplinary group of seven graduate students from Texas A&M University College of Architecture and the Department of Civil Engineering conducted a study under the supervision of Dr. Xuemei Zhu from the college of Architecture to create design guidelines for the Colony Park master plan. The research project was broken into two phases. Phase I attempted to determine and measure the site components found within the Mueller neighborhood that promote, or hinder an active living lifestyle. Phase II of the project reviewed the information and data acquired from studying the Mueller community and applied the results to create design guidelines for the Colony Park master plan in Austin, TX. To accomplish this objective, the research team used the following sources in Phase I:

- The city of Austin and Mueller design guidelines
- Aerial photography
- GIS data obtained from Texas A&M University, and the city of Austin planning department
- GIS data created by project team members based on aerial photography, and field work.
- Field audits
- Literature review

In Phase II, the project team summarized the six "Livability Principles" listed above into Health, Sustainability and Economics. Focusing on the health aspects, the research team created four design guideline focuses on:

- Land development patterns
- Parks, greenways, and open spaces
- Street systems
- Building and urban design

© ASCE 2014

PHASE I - ACTIVE LIVING FEATURES IN MUELLER NEIGHBORHOOD

Land Development Patterns

In phase I, Mueller PUD Ordinances were compared with Austin City Codes and LEED-ND guidelines to determine how well strategies were implemented. From this review, it appears strategies were employed beyond the minimum standards.

The Mueller PUD Ordinance does not contradict, nor does it modify many of the city ordinances relating to parklands. Rather, it details in (D)(5)(a) of the PUD Ordinances that Austin City Code §25- 4-212/as governed by §25-1, Article 14 relating to Parkland Dedication has been "modified to provide that approximately 68 acres of the PUD area…shall be dedicated to the city as parkland (The Code of the City of Austin 2013) (Mueller PUD Ordinances, 2004)." The Austin City Code specifies in §25-3-77: Parkland Dedication that "the amount of land required to be dedicated for parkland is 25 percent of the open space in a traditional neighborhood district," while §25-1-602, Article 14: Dedication of Parkland Required states that "The amount of parkland required to be dedicated to the city is five acres for every 1,000 residents (The Code of the City of Austin 2013)." The LEED-ND guidelines on the other hand do not define the amount of parkland that should be reserved to achieve set standards. This is an aspect that has been left to local governments to regulate. Since the total projected population for the neighborhood is 13,000 residents, this entails that 65 acres of land needs to be dedicated to the city as parkland. The Mueller development has set aside a total of approximately 140 acres of parks, trails and open space (ROMA Design Group 2004). Altogether this equates to twenty percent of the total land area in the neighborhood that is to be designated for such uses. Of this land, the Northwest, Southwest, and Southeast Greenways will all be dedicated to the City of Austin as parks, equaling the approximately 68 acres of the PUD area mentioned earlier (Mueller PUD Ordinances 2004), and thus achieving the requirements of the city ordinances.

The Mueller PUD Ordinances discuss mixed-use districts as being incorporated into the Town Center. It is described as a mixed-use district providing neighborhood retail/commercial and service uses along a pedestrian-oriented shopping street and multiple sites for higher density office, residential housing, and civic uses. Mixed-use buildings are permitted (Mueller PUD Ordinances, 2004). Mixed-use areas are described by the Austin City Code as pertaining to the downtown, and as a "designation for a use located on the periphery of an area that has a CBD designation." The definition of traditional neighborhood (TN) districts is more fitting for Mueller, as it is a "compact, mixed-use development that reflects the urban design practices that existed in the United States from colonial times until the 1940's (The Code of the City of Austin 2013)."

Parks, Greenways, and Open Spaces

The research team reviewed the proposed parks and open spaces proximity in Mueller and compared it to recommendations from the current literature. Based on the literature review, 1/2 mile is the recommended park service radius. After analyzing the Mueller community, the research team conclude that all Mueller

© ASCE 2014

residents are living within 1/4 mile of a park, which meets the recommended proximity requirement for promoting active living.

The research team also analyzed the accessibility between each important node (important viewing place, activity space, or infrastructure) within the park or open space and depicted the desired characteristics of the park entrance that promote accessibility. To accomplish the first objective, the trails, water feature boundary, important nodes, and trail entrance points of all parks and open spaces that have been built were traced and marked based on the site plans and Google Earth Maps. From the analysis, the research team determined the following principles were applied to the site:

1. Every important node connects with one or more directional trails, which makes it more accessible to the public.
2. Several loop trails link with one another, providing multiple choice for people to access their interesting destination.
3. Trails were placed along the waterfront to increase water access opportunities.
4. If the park surrounding context is similar, it is better to distribute trail entrance points evenly.

Next, the research team analyzed the Mueller design to determine the overall pattern of parks and open space systems and the advantages and disadvantages of the current design. The research team created a map in ArcMap 10.0 of the proposed parks and open space system within the Mueller boundary as well as city level parks at its surrounding area. The open space system is approximately 140 acres, which comprises more than 20 percent of the total property. Figure 1 shows parks, greenways, and open spaces within the Mueller Community and outside of it. The open space system is approximately 140 acres, which comprises more than 20 percent of the total property. As Figure 1 shows, the proposed open space system links with the existing city level surrounding park system. This illustrates the kind of open space that potentially serves not only Mueller residents, but also its surrounding neighborhoods. Also open spaces are distributed relatively evenly (except for the northwest side). It provides opportunities for people from all directions to get there. The smaller scale open spaces, pocket parks, are evenly scattered throughout the community. These forms of spaces mainly serve Mueller residents. Neighborhood parks of approximately two to three acres in size are planned as the principal focal points and gathering spaces for each of Mueller's four neighborhoods.

Finally, Figure 1 shows that series of smaller pocket parks of approximately one-quarter to one acre in size are also planned within each neighborhood. These pocket parks are located so as to ensure that all residents are within 600 feet of a park and configured to create a focus for neighborhood subareas. These parks were designed to serve the special recreational interests of the community, and reflect the demographic characteristics of each neighborhood. Despite the small size of this kind of open space, it nevertheless plays an important role. Due to the proximity issue, the frequency of using such open spaces is high. Also from a parental perspective, they may feel that it is safer to let their children to play in these kind of parks since most users are Mueller residents and not strangers.

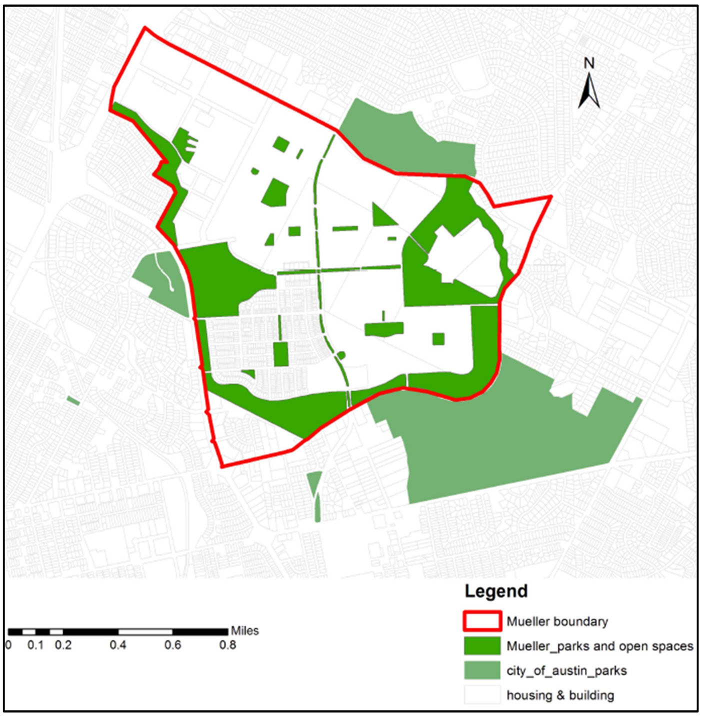


Figure 1. Distribution of parks, greenways, and open spaces within the Mueller Community and outside of it.

Street Systems

Several important elements have been identified in shaping a healthy community, such as walkable streets, mixed land uses, easy access to recreation facilities, connected street networks, etc. This study focused on transportation systems, especially on street pattern and transit-oriented development. A connected street pattern usually features a grid-like structure. It is a simple system of several sets of parallel and vertical roads to shape rectangular blocks. A grid-like street pattern increases walking and biking behaviors by offering direct routes to destinations, many short links, and numerous intersections.

As shown in Figure 2, the street pattern in Mueller belongs to a grid pattern with a hierarchical design. There is no cul-de-sac in the road system and all streets are well connected. The grid pattern provides multiple connections to distribute an even vehicle traffic through the street system and to extend the open space system and the pedestrian and bicycle networks. According to these characteristics, this design is expected to produce more physical activity. Moreover, within areas around transit stations, various housing types are provided to enhance density and most buildings orient toward streets and transit. Streets are well-connected with pedestrian-friendly sidewalks and back alleys.

Literature states that high street connectivity is a critical factor in walkability and has been positively associated with residential activity patterns (Frank et al. 2010; Nelson et al. 2006). These authors defined connectivity as neighborhood street networks that are continuous, integrated, and maximize linkages between starting points and destinations, providing multiple route options. Connected and open

© ASCE 2014

community is one of the prerequisites of the LEED ND rating system. Connectivity in this rating system is defined as the number of publicly accessible street intersections per square mile, including intersections of streets with dedicated alleys and transit rights-of-way, and intersections of streets with no motorized rights-of-way. In this study, we used the equations for measuring street connectivity. The equations are as follows:

1. Street Density= total footage of streets / total acres of the area
2. Street Intersections Density= number of street intersections (3-way)/ total acres of the area

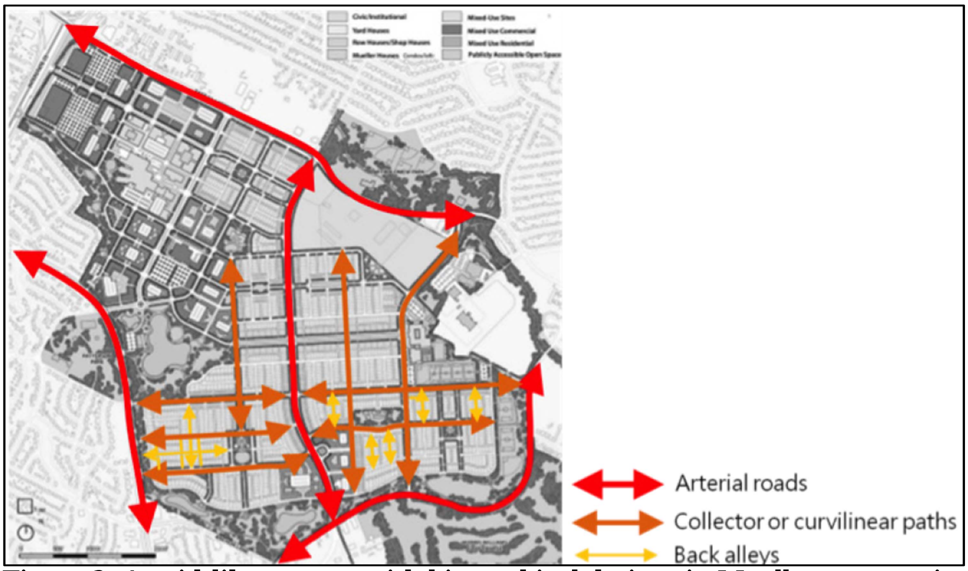


Figure 2. A grid-like pattern with hierarchical designs in Mueller community

LEED for Neighborhood Development suggest that internal connectivity should be at least 140 intersections per square mile, which is equal to 0.22 (140/640 acre). Street intersections density in the Mueller community is higher .594 and makes this project qualified for one LEED credit. In a study for linking objectively measured physical activity with objectively measured urban form, Brownson et al. (2009) recommended street intersections density of at 30 intersections per square kilometer, which is equivalent with 0.12 intersection points per acre (30 / 247.105 acre = 0.12). Mueller community exceeds this minimum ratio as well.

Building and Urban Design

This portion reviewed streetscape patterns and their influence on walkability and healthy communities. These streetscape patterns were studied are from building edge to street edge and the space between these. Determining specific streetscape pattern guidelines can be tricky as certain local issues may make guidelines that work in one city obsolete in another. But there are certain specifics that appear to be uniform across the board in improving walkable communities. These include building setbacks, building frontage, buffer zones between pedestrians and vehicles, sidewalks, vegetation, shade, and parking. Pedestrians feel a sense of safety when these are applied to their communities. Lack of sidewalks, large setbacks, fast moving traffic and no buffers deter walking. In this study, the research team focused on

© ASCE 2014

housing setbacks, apartment setbacks, commercial area setbacks, and sidewalk widths.

After reviewing and analyzing actual Mueller conditions compared to Mueller Design Guidelines and Austin's Design Guidelines, an example of which is shown Figure 3, it was determined that the site accomplished creating an environment that would foster greater active and physical living. When looking at Austin's guidelines, there were many instances that determined the ideal buffer and sidewalk widths and design elements. Yet, at the same time, there were not many guidelines in determining appropriate housing setback. This is something that Austin should consider revising as housing and building setback have been shown to promote a more neighborly atmosphere which encourages more walking and less vehicular usage. Mueller's guidelines were very specific when it came to development guidelines. This was done to ensure the community had an overall feel to it that made it easily identifiable. While quite detailed, these guidelines have so far been successful in areas that have been developed. The built up areas follow the design patterns that research has shown will increase physical activity and will help Mueller become a healthy community.

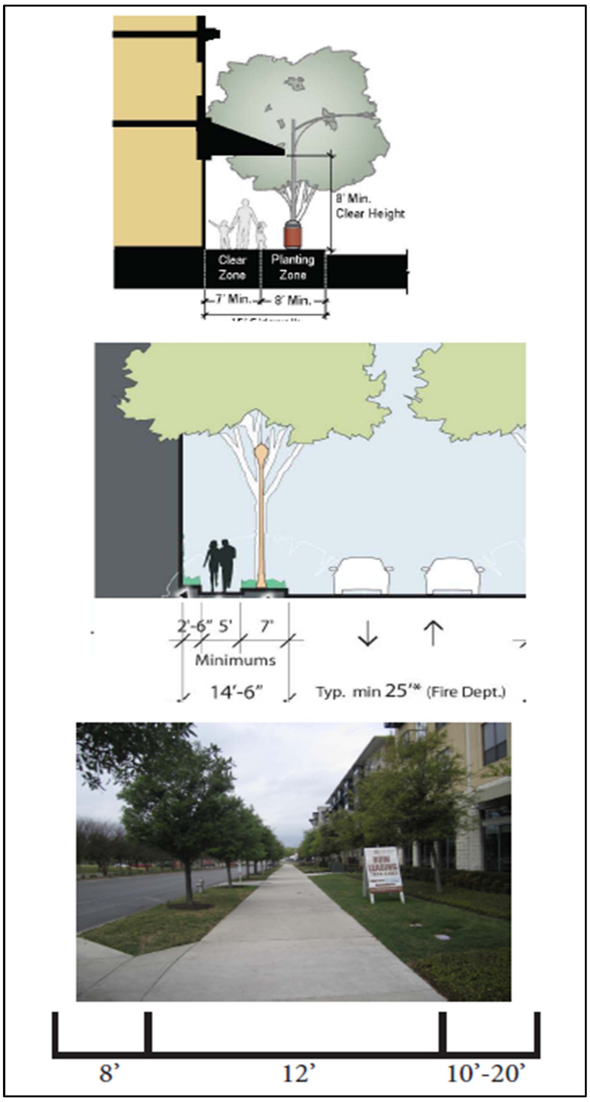


Figure 3. Comparison of design guidelines to actual conditions in Mueller Community.

The research team also looked at the role of building and urban design in community safety. Safety and scale are both important aspects of urban, landscape, and building design because they interweave throughout many elements and subsystems in the design. For example, scaling the width of a street to an appropriate level in a community can help to improve the safety in that area. The level of safety that is perceived as well as the scale of objects and facilities can impact patterns that are used in the land, how much parks and open spaces are used, the effectiveness of transportation systems (not just for motorists, but also for pedestrians and other non-motorists), and other urban planning and design measures. Although one could possibly interpret safety or scale in different ways, for the purposes of this study, safety and scale can be considered as described here.

© ASCE 2014

- Safety is an aspect of design that can aid in reducing the potential for harm or the perception of harm.
- Scale is an aspect of design that seeks to closely match physical objects and facilities as well as time-oriented design features (such as how fast you can get from point A to point B) to the size and proportion of humans (Ewing et al. 2006)

The more safe a community is and the better scale it provides is likely to encourage more active and healthy living. This is because people can feel more secure and connected to a community that is safer (and perceived to be safer) and sized to best meet their needs. The more secure and connected they feel offers a greater chance that people will want to walk along the streets or sidewalks, take advantage of the parks and open areas for different kinds of physical activity, or visit the local businesses. The evaluation used a photo inventory to assess safety and scale design features in areas where apartments were located, where single family homes were located, and where commercial areas were located. Based on this analysis, there were several areas found that the Mueller Community should sustain and several areas that could be improved. Much of the lighting, walkway clearances, and streetway widths were sized and spaced to promote a safe and healthy community. Gating was used intermittently and could be enhanced in future.

The Mueller Community has many design selections that enhance a positive safety and scale, such as courtyards, lighting, and prominent walkways. Some areas were identified that could potentially make improvements in the existing community, including adding more traffic circles, reduction of vehicle-centric parking, and expansion of storefront widths to accommodate tables instead of just benches. The crime from calendar year 2012 in the areas of the Muller Community indicated a larger amount of thefts and burglaries than other crime. Attention should be focused in the locations identified to help reduce those crimes in the future.

PHASE II – DESIGN GUIDELINES FOR COLONY PARK DEVELOPMENT

Land Development Patterns

The proposed Colony Park development sits on a parcel of land near existing and established neighborhoods. Land uses should relate to the surrounding neighborhoods, so that a bond may be formed between the established communities and the new Colony Park Development. Before any analysis is performed, the extents of the area we are examining must be determined. These relate to how far the proposed development will affect surrounding communities. For our purposes, the zip-code for Colony Park was used. This distance takes into account those individuals that live closest to Colony Park and will be affected the most by development; essentially a walking distance of ¼ to ½ mile (Zimring et al. 2005). It also takes into consideration automobile and public transportation users who would likely benefit from amenities or jobs obtained from within the area. This information was used for the U.S. Census tool, On the Map to collect economic data. By utilizing American FactFinder, demographic information was able to be gathered giving a clearer picture of the neighborhoods surrounding Colony Park. According to the data U.S. Census, a total of 21,696 individuals live in the 78724 zip code (United States Census Bureau

© ASCE 2014

2013). It fully encompasses the Colony Park proposed development area which is central to it. The population density within this area is 822.71 persons/ sq. mile (78724 Zip Code, 2013)

Ideally, residential areas should surround a core with mixed-uses that contain jobs, shopping, amenities, entertainment, restaurants, etc. That would allow the newly built residential areas to act as a buffer to the established neighborhoods. It would also create a subtle transition from the single-family neighborhoods to the denser core of Colony Park. Due to the number of families (4,473 family households) living in adjacent communities, adequate parks and recreational facilities are necessary and should be placed within close proximity and easy access to existing dwellings. Current land-use trends do not reflect desired densities for Colony Park. They should be considered though because the infrastructure is reflected by what it presently sustains. Therefore, a large burden should not be placed upon the infrastructure system (i.e. roads, water, sewage, educational facilities, etc.). Forming an area with too high of densities could immediately become problematic. The research team recommend the following guidelines:

- Town Centers should act as employment hubs to help create a boost to the local economy and provide for the needs of the surrounding neighborhoods.
- Proximity of residential land-uses to public transportation stops should be between ¼ - ½ mile (Zimring et al. 2005).
- Encourage a concentration of mixed land-uses, especially along main thoroughfares (New Jersey Department of Transportation 1994).
- Parking garages should be used instead of surface parking in mixed-use areas to "provide opportunities for shared parking and create transit destinations (New Jersey Department of Transportation 1994).
- Multiple parks and open spaces should be located within one mile of residents in Colony Park and adjacent neighborhoods, with parks located at ½ mile distances of more densely populated areas or areas of lower-income populations (Mowen 2010).
- Parks and open spaces should be located in areas with the greatest visual accessibility so that the perceived access in relation to distance of these areas seems less, and thus physical activity will increase (Mowen 2010).
- Playgrounds and recreational facilities should be included in every multi-family area of 100 units or more.
- All residential units should be between two to three stories tall so that units do not contrast dramatically with older homes around Colony Park. Single-family dwelling densities should be between 6-12 units per acre and multi-family unit densities of 60-80 units per acre (Department 2013).

Parks, Greenways, and Open Spaces

Based upon the existing parks and open spaces analysis, a narrative guideline with visual graphics for Colony Park was created to accurately depict the way in which parks and open spaces promote physical activity from four aspects. This includes proximity, accessibility, park pattern, and recreational facilities:

- Proximity: use 1/2 mile as recommended park service radius

© ASCE 2014

- Accessibility: within a park, trails should connect each rest area and several loop trails should be provided that link with one another to provide multiple choices for people to get their destination. At trail entrance points, it would be best to design some features, such as curb cuts, crosswalks, traffic signals, pedestrian signals and signage, curb extensions, signage, while removing or moving the existing obstacles, like utility facilities.
- Pattern: Design greenways in a relatively large area surrounding the whole community as a protective buffer zone and design several small scale (1/4 to 5 acres) neighborhood parks and pocket parks within each neighborhood to provide recreational gathering spaces for community residents only.
- Recreational facilities: provide some recreational facilities for intensive physical activities, such as multi-use playfields, sports fields, game courts, swimming pool, field house, bicycle rental concessions, and also provide recreational facilities for special events, like outdoor theaters, amphitheaters, etc. for trails, running grade should be less than 5 percent and rest areas should exist at maximum intervals of 400 ft. Maximum trail slope is 5 percent and at least 100 inches of vertical clearance should be provided on a trail. Provide shade with trees on both side of the trails.

Street Systems

Based on the results of Phase I analysis, literature review, and analysis of information collected about the Colony par development, the following strategies are recommended for Colony Park:

- Results of Phase I showed that one key planning strategy that improved the street connectivity in the Mueller Community was using grid street pattern with interconnected streets and sidewalks. The research team recommends street connectivity should be between 200-250 feet.
- The topography of Colony Park is quite different than found in Mueller. While Mueller is situated on an abandoned airport, meaning a generally flat landscape, Colony Park is located in the hills of Austin, necessitating grade changes that can have an influence on street layout. Laying streets out diagonal to diagonal to the contours creates moderate slopes in all streets and eliminate the negative impact of the topography on walking and cycling.
- Moreover, planners should encourage local businesses around transit stops to offer attractive destinations. Dead-end streets and cul-de-sacs should be avoided and back alleys should be used when possible. Cul-de-sacs make long travel distances even to close destinations and decrease walking and cycling rates. Phase I analysis of the Mueller Community indicated that back alleys provided good connections with other streets and also a safe place for children to play.

Building and Urban Design

Several design guidelines were presented based upon lessons learned from the Mueller Community analysis, the literature review, and subject matter expertise. Each of these were evaluated with strategies that would promote the goals of planning a safe community and a community with human scale. The strategies used in providing a safe community included neighborhood surveillance, access control, territorial reinforcement, and maintenance. The strategies used in providing a community with

© ASCE 2014

human scale include prominence, widths, visibility and speed. The following specific design guidelines are selected to help meet above strategies that were identified that would help the community achieve its goals:

- Use flush and bright building façade with lighting. A brighter façade can help people in the community see silhouettes of potential danger. Minimizing nooks and keeping a flush façade will help facilitate proper maintenance, extending the buildings lifecycle and improving the perception of the community.
- Use big windows and provide open and clear street front and courtyards to aid promotion of neighborhood surveillance. Courtyards can be used to promote physical activity in residential areas and promote pedestrian-centric designs in commercial areas.
- Provide manicured, open, and clear landscaping to reinforce territorial prominence, aid in neighborhood surveillance, and improve visibility. The scale should be supportive of the natural and built environments.
- Promote pedestrian-centric design opportunities by providing clear traffic circles and speed hump. Prominence and widths of devices such as traffic circles and speed humps helps improve visibility and regulate speed.

CONCLUSION

The criteria of what a healthy and walkable community is can vary among individuals and governmental agencies. Numerous cities have developed their own standards in ways to tackle the ever-growing suburban sprawl and the over reliance that individuals have on automobiles. For the past twenty years several new thought processes have emerged to change the current mode of suburban sprawl development to encourage New Urbanism and Smart Growth. Cities have been working with researchers and developers to showcase how these traditional developments can have to improve neighborhood and community design to increase walkable communities. These organizations have determined that several factors affect community walkability, from land use, to road networks, and streetscape patterns.

Mueller is an excellent example of how sound planning and design can influence community development in a positive notion. With city influence, designer input, and local residents concerns all addressed, Mueller is a radical approach in the way that Austin has been developed for the past 50 years. And yet, even with these changes, there are numerous design elements that again may need upgrading to what "sustainable" development means now. Colony Park is the type of development that can improve on what Mueller has already been able to accomplish and to demonstrate how planning and design can lead to better, healthier communities.

REFERENCES

Brownson, R. C., Hoehner, C. M., Day, K., Forsyth, A., and Sallis, J. F. (2009). "Measuring the built environment for physical activity." *American Journal of Preventive Medicine*., 36(4), 9.

Department, L. A. H. (2013). "Housing density. What do you mean when you talk about density?",

© ASCE 2014

<http://lahd.lacity.org/lahdinternet/Portals/0/Policy/curriculum/gettingfacts/design/density.html>. (April, 11, 2013).

Duany, A., Plater-Zyberk, and Jeff, E. S. (2010). *Suburban nation : the rise of sprawl and the decline of the American Dream*, North Point Press, New York.

Elkin, T., McLaren, D., and Mayer, H. (1991). *Reviving the City : Towards Sustainable Urban Development*, Friends of the Earth with Policy Studies Institute, London.

Ewing, R. (1997). "Is Los Angeles-style sprawl desirable?" *Journal of the American Planning Association*, 63(1), 107-126.

Ewing, R., Handy, S., Brownson, R. C., Clemente, O., and Winston, E. (2006). "Identifying and measuring urban design qualities related to walkability." *Journal of Physical Activity & Health*, 3, S223-S240.

Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., and Hess, P. M. (2010). "The development of a walkability index: Application to the Neighborhood Quality of Life Study." *British Journal of Sports Medicine*, 44(13), 924-933.

Frumkin, H., Lawrence, F., and Richard, J. (2004). *Urban sprawl and public health designing, planning, and building for healthy communities*, Island Press, Washington, DC.

Gartland, L. (2008). *Heat islands : understanding and mitigating heat in urban areas*, Earthscan, London; Sterling, VA.

Grant, J. (2002). "Mixed use in theory and practice: Canadian experience with implementing a planning principle." *Sage Urban Studies Abstracts*, 30(2), 143-275.

Heimlich, R. E., and Anderson, W. (2001). "Development at the urban fringe and beyond: Impacts on agriculture and rural land." U.S. Department of Agriculture, Economic Research Service, Washington, DC.

Johnson, M. P. (2001). "Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda." *Environment and Planning*, 33(4), 717-735.

McKenzie, E., Money, J., Green, P., and Young, T. (2009). "Metals associated with storm water-relevant brake and tire samples." *Science of the Total Environment*, 407, 5855–5860.

Mowen, A. J. (2010). "Parks, Playgrounds and Active Living." Robert Wood Johnson Foundation, Princeton, NJ.

Mueller PUD Ordinances (2004). "Ordinance No. 040826-61." Approved by the City of Austin, Austin, TX.

Nelson, M. C., Gordon-Larsen, P., Song, Y., and Popkin, B. M. (2006). "Built and social environments associations with adolescent overweight and activity." *American Journal of Preventive Medicine*, 31(2), 109-117.

New Jersey Department of Transportation (1994). "Planning for Transit-Friendly Land Use: A Handbook for New Jersey Communities."Trenton, NJ.

ROMA Design Group (2004). "Mueller Design Book." City of Austin, Catellus Development Corporations, Austin, TX.

Smith, J. E., and Perdek, J. M. (2004). "Assessment and Management of Watershed Microbial Contaminants." *Critical Reviews in Environmental Science and Technology*, 34(2), 109-140.

Stone, B. (2008). "Urban sprawl and air quality in large U.S. cities." *Journal of Environmental Management*, 86(4), 688-698.

The Code of the City of Austin (2013). "austintexas.gov: The Official Website of the City of Austin." American Legal Publishing Corporation Austin, TX.

The Sierra Club (1998). *The dark side of the American dream : the costs and consequences of suburban sprawl*, Sierra Club, San Francisco, CA.

United States Census Bureau (2013). " American Fact Finder." <http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml>. (April, 10, 2013).

© ASCE 2014

United States Department of Housing Urban Development (USHUD) (1999). "The state of the cities 1999 : third annual report." U.S. Dept. of Housing and Urban Development, Office of Policy Development and Research, Washington, D.C.

Zimring, C., Joseph, A., Nicoll, G. L., and Tsepas, S. (2005). "Influences of building design and site design on physical activity: research and intervention opportunities." *American journal of preventive medicine*, 28(2), 186-193.

© ASCE 2014

Social physics techniques for meeting ITS deployment challenges in cities of emerging economies

Kelsey L. Lantz[1], Leidy E. Klotz[2] and Mashrur A. Chowdhury[3]

1. Glenn Department of Civil Engineering, 109 Lowry Hall, Clemson University, Clemson, SC 29634; PH (724) 825-5951; FAX (864) 656-2670; email: klantz@g.clemson.edu
2. Glenn Department of Civil Engineering, 109 Lowry Hall, Clemson University, Clemson, SC 29634; PH (610) 247-9067; FAX (864) 656-2670; email: leidyk@g.clemson.edu
3. Glenn Department of Civil Engineering, 109 Lowry Hall, Clemson University, Clemson, SC 29634; PH (864) 508-0002; FAX (864) 656-2670; email: mac@g.clemson.edu

ABSTRACT

Intelligent transportation systems (ITS) use information technology to improve the safety and efficiency of surface transportation mobility. Emerging cities that are still in the early phases of infrastructure deployment have an opportunity to leapfrog directly to ITS applications that have already been proven to be successful elsewhere. One challenge, however, is lack of availability of real-time traffic data, which is important for the planning and monitoring of most ITS applications in these developing cities. This paper describes how data collected from mobile phones and analysis techniques from the new field of social physics, which is defined as the modeling of human behavior through aggregation of big data could be used to respond to this challenging lack of useful data. Few studies have indicated that use of cell phone data and application of social physics might help overcome the lack of data obstacle to ITS deployment in cities of emerging economies. Although further study is needed, widespread cell phone usage and the corresponding GPS data suggest other emerging cities may benefit from similar approaches. This paper discusses the potential of integrating cell phone data with social physics for providing the real-time traffic data for ITS applications in cities that would benefit from it the most.

INTRODUCTION

Data collected from mobile phones and analysis techniques from the new field of social physics could be harnessed to respond to the lack of data challenge in ITS applications. ITS contributes to the wellbeing of the city by combining information technologies with transportation management in a way that reduces vehicle emissions, provides information that encourages more environmentally friendly travel

© ASCE 2014

behavior, and by replaces activities through telecommunications that formerly required travel (Rami Puzis et al. 2013). By improving the efficiency of transportation, ITS can reduce vehicle emissions and thus improve air quality, which is a pressing concern in the developing world where older vehicle fleets and weak emissions standards often plague the sensitive urban environment (Garrison 2000). Previous studies have shown that ITS provides sustainable mobility in terms of reducing energy consumption and air pollution (Lee Tupper et al. 2012) (Yanz Zhou et al. 2010).

An urban area's economic and social health largely depends on the performance of its transportation system. Not only does the transportation network provide opportunities for the mobility of people and goods, but it also influences patterns of growth and the level of economic activity through the accessibility it provides to land in the long run. In addition, it connects to other urban areas, to a country, and to the world. Recently, changes to the urban transportation systems have been treated by many public officials as a means of meeting a variety of national and community objectives. Such changes have been motivated by the desire to improve air quality, enhance the viability of economic activity centers, provide services to those needing mobility, and promote more sustainable community development. Planning for the development or maintenance of the urban transportation system is therefore an important activity, both for promoting the efficient movement of people and goods in a metropolitan area and for providing a strong supportive role in attaining other community objectives. This planning does not take place accidentally; it must be part of a dedicated effort to allocate resources for unified transportation objectives. These objectives must recognize the need for smarter growth of transportation systems, as reckless expansion will not solve the complex social and environmental challenges that plague contemporary cities.

As cities in transitional countries experience unprecedented growth, their transportation systems are heavily strained by the rapidly increasing demand for mobility. Concurrently, the penetration of GPS-based navigation systems is growing. Proper urban transportation planning can insulate cities from the negative impacts of rapid growth in mobility demands. Information technology can pave the way to smarter planning, even in developing cities. Recent research shows that average speed and delay estimates, which are common transportation planning benchmarks, are insufficient to capture the environmental impacts of ITS adaptive signal control; therefore we must improve our monitoring techniques to better assess impacts and plan for future developments ("Intelligent Transport Systems (ITS) for Sustainable Mobility" 2011). We recommend taking advantage of the opportunity to leverage emerging GPS data for transportation monitoring and planning. Smarter planning will yield safer and more effective systems in order to properly mobilize the rapidly growing urban populations in the developing world.

CHALLENGES TO IMPLEMENTING ITS IN THE DEVELOPING WORLD

Cities that do not fall under the category of "industrialized" face many unique challenges with respect to urban mobility. Their urban transportation policy, if in existence, is largely shaped by political forces that inhibit constructive change. Weak

© ASCE 2014

institutions cripple standardization and planning development, while existing infrastructure is rarely maintained. Social and organizational barriers also inhibit the adoption of transportation interventions that are successful elsewhere in the world. For example, there may not be a social custom of obeying traffic laws or an effective traffic law enforcement system (Winston 2005).

The provision of adequate transportation infrastructure is a routine challenge for growing cities in the developing world. Hurried adoption of ITS strategies in these cities has consistently failed to deliver the desired outcomes due to a predictable lack of planning and management. Regional and national transportation authorities often face a confusing mix of ITS offerings from various industries, some of which are incompatible with local circumstances. Alternatively, locally produced technology can often be of debatable quality. Developing countries face a number of problems in the deployment of ITS, as summarized below (Akhtar All Shah and Lee Jong Dal 2007):

1. **Non-availability of supportive instrumental framework** to efficiently enforce the institutional arrangements for the realization of ITS benefits. For example, a weak police force in Manila has enabled a situation where only five out of forty speed measurement units remain functional due to breakdown or theft.
2. **Unavailability of basic data** such as volume and speed in order to diagnose traffic problems.
3. **The adoption of imported applications** often diverge from local technological and human resource capacity
4. **The indifferent attitude** of many professionals whom lack knowledge of the potential of the ITS application
5. **Lack of trust** from users regarding claimed benefits
6. **A legacy of failure:** the ITS deployment in several countries has not followed straightforward policy guidelines that resulted in the failure of many applications.

As noted in the second problem in ITS deployment, an extensive challenge to the development of safe and effective transportation systems is the perpetual lack of availability of transportation systems and traffic data in these developing cities. This is most solvable by employing a new approach based on social physics. Social physics is the modeling of human behavior through aggregation of big data, which is readily available in our present age of information (Yaniv Altshuler et al. 2011). This idea has wide-ranging applications, but is especially relevant to easing the costly and often ineffective transition to ITS in developing cities. Data regarding transportation preferences for planning purposes has traditionally been collected through dauntingly expensive and tedious survey methods. There is a strong need for developing an alternative method for assessing mobility and traffic demand in transportation network that can be easily adopted by developing cities. This particular challenge to deploying ITS applications in transitional countries can be addressed by a novel approach rooted in social physics.

© ASCE 2014

TRANSPORTATION NETWORK DATASET

An increasingly widespread technology worldwide, the mobile phone, can be used to affordably collect data without expensive new data collection systems. Analysis of the urban mobility data can aid ITS deployment strategies within developing cities. This data accurately reflects individual choices and trips taken, and can be used to drastically improve our understanding of a city's greatest transportation challenges and strengths. *Betweenness Centrality* (BC) is a theory that indicates the ability of an individual node, or part of a transportation system, to control the communication flow in the transportation networks that can be collected through mobile phone data (Yaniv Altshuler et al. 2011). Recently, BC has been applied to analyze various complex networks, including social networks, computer communication networks, and protein interaction networks (Yaniv Altshuler et al. 2011). Studies have shown that in particle hopping systems like traffic, BC, or the measure of connectedness between individual nodes, is highly correlated with congestion. Therefore, it has many possible applications for the forecasting of mobility patterns in transportation networks and predicting future congestion problems based on existing travel behavior. An example of a transportation network dataset in Israel shows how the use of cell phone data and application of social physics might help overcome the lack of data obstacle to ITS deployment in developing cities. This study was conducted to relate BC and traffic flow based on Israeli transportation data collected from cell phones. This is an excellent case study for using mobile communication technology to ease the transition to intelligent transportation infrastructure in developing cities because there can be a sufficient return on the investment.

Effective transportation planning relies on accurate and current data that reflects traffic flow, vehicle fleet composition, and emission measurements; the acquisition of which can be elusive in the developing world. In order to accurately estimate the effect of a specific network change on the total emissions produced by vehicles within the network, examination of the vehicle fleet composition for each unit of analysis is needed. Other problems, like finding optimal deployment of traffic monitoring systems, can be difficult to solve but can have far-reaching economic and environmental benefits to the city.

Mobile phone technology is becoming ubiquitous in even the most underdeveloped nations of our world, enabling the collection of affordable and accurate traffic data. Cell phone market penetration is especially high among people between the ages of 10 and 70, the main range of focus for travel behavior studies. Such high penetration enables a broad study of travel behavior that is based on the mobility patterns of randomly selected mobile phones in the Israeli transportation system. In this study, the data was shown to provide very high quality coverage of the network, tracking 94% of the trips. This resulted in a wealth of traffic properties for a network containing over 6,000 nodes and 15,000 directed links. Additionally, the network has an Origin Destination (OD) matrix, which specified the start and end points of all trips (Yaniv Altshuler et al. 2011).

The network was created in order to supplement the National Israeli Transportation Planning Model. In urban areas, the network includes arterial streets

© ASCE 2014

connecting interurban roads. Each link includes information regarding the length, hierarchical type, free flow travel time, capacity, toll, hourly flow, and congested travel time. The hourly flows and congested travel times were obtained from a traffic assignment model that applies the OD matrix to the network links (Yaniv Altshuler et al. 2011).

This dataset creates a network structure, which is used to perform accurate high-level traffic analyses reflecting traffic flow and congestion on individual links. Mobility patterns indiscernible through traditional methods of data acquisition become clear through the social physics approach. Conventional methods of acquiring traffic data through sensors are expensive and often unreliable. Optimal deployment of monitoring units maximizes their utility, which is important for underdeveloped cities with constrained financial resources.

An Israeli traffic study related the BC of a node to its expected traffic flow within the transportation network. By using a comprehensive mobile-sourced dataset that covers the Israeli transportation network, the authors performed a simple analysis of the network and its properties to demonstrate a correlation between the traffic flow and their BC. By taking into account that a large portion of the traffic occurs during rush hours and that roads serve a variety of purposes to the community, it has been shown that the accuracy of the model can be improved by clustering the roads into groups based on their types, while weighting the data that is associated with specific hours.

CONCLUSION AND EXPECTED IMPACTS

Considering the critical role of mobility in the economic growth and prosperity and the importance of technology in assisting both industrialized and emerging economies, a hands-off approach to mobility is neither recommended nor desirable. The parallel development of information and telecommunication monitoring systems can ease the difficult transition to safer and more effective transportation systems through the deployment of ITS technologies. While further study is needed, widespread cell phone usage and corresponding automatically collected, anonymous GPS data suggest other developing cities may benefit from similar approaches where social physics facilitates the analysis of these data for generating real-time traffic data. Developing cities are in dire need of a strategy to ease the transition to intelligent transportation technologies in spite of social and institutional limitations, and analyzing traffic behavior data to predict mobility patterns is one cost effective method to do so.

© ASCE 2014

REFERENCES

Akhtar All Shah, and Lee Jong Dal. 2007. "Intelligent Transportation Systems in Transitional and Developing Countries." *IEEE A&E Systems Magazine*, August.

Garrison, William L. 2000. *Tomorrow's Transportation: Changing Cities, Economies, and Lives*. Artech House ITS Library. Boston: Artech House.

"Intelligent Transport Systems (ITS) for Sustainable Mobility." 2011. UNECE.

Lee Tupper, Mashrur Chowdhury, Leidy Klotz, and Ryan Fries. 2012. "Measuring Sustainability: How Traffic Incident Management through Inteligent Transportation Systems Has Great Energy and Environmental Benefits than Common Construction-Phase Strategies for 'Green' Roadways." *International Journal of Sustainable Transportation* 6 (5).

Rami Puzis, Yaniv Altshuler, Yuval Elovici, Shlomo Bekhor, Yoram Shiftan, and Alex Pentland. 2013. "Augmented Betweenness Centrality for Environmentally Aware Traffic Monitoring in Transportation Networks." *Journal of Intelligent Transportation Systems* 17 (1): 91–105.

Winston, Clifford. 2005. "Government Failure in Urban Transportation." *Fiscal Studies* 21 (4): 403–25. doi:10.1111/j.1475-5890.2000.tb00030.x.

Yaniv Altshuler, Rami Puzis, Yuval Elovici, Shlomo Bekhor, and Alex Pentland. 2011. "Augmented Betweenness Centrality for Mobility Prediction in Transportaiton Networks." In Athens, Greece.

Yanz Zhou, Lee Tupper, Mashrur Chowdhury, and Leidy Klotz. 2010. "Green Credits Vs. Sustainable Traffic Operations: A Comparison of Contributions to Energy and Emissions Reductions." *Transportation Research Record: Journal of the Transportation Research Board* 2163: 103–11.

© ASCE 2014

Case Studies in Sustainable Urban Stormwater Management Design and Innovation

Jamil Bou-Saab, P.E.[1] and Christopher Miehle[2]

[1]TERRA Engineering Ltd., 225 W. Ohio, 4th Floor, Chicago, IL 60654; PH (312) 467-0123; FAX (312) 467-0220; email jbousaab@terraengineering.com
[2]TERRA Engineering Ltd., 225 W. Ohio, 4th Floor, Chicago, IL 60654; PH (312) 467-0123; FAX (312) 467-0220; email cmiehle@terraengineering.com

Abstract

The purpose of this paper is to outline strategies of sustainable stormwater management design and innovation for private developments and public infrastructure projects in urban areas. This paper will focus on urban stormwater management, with several examples of private and public projects recently completed that implement sustainable stormwater management design. Through examination of specific projects this paper will assist the audience in understanding current local trends for sustainable stormwater management, provide information on local agency requirements for their implementation, and foster a discussion of techniques to change the current way of thinking in their application in public and private infrastructure projects. This paper is based on the authors' experience as an engineer and designer of sustainable stormwater management systems as well as review of current literature addressing sustainable stormwater management.

I. Introduction

Managing stormwater has been part of human's interaction with their environment for millennia. Humans have used numerous methods to prevent damage from flooding and erosion caused by stormwater during rainfall events. Typical stormwater management controls consist of structural and non-structural elements that contain and convey stormwater during a rain event. These typical stormwater management controls can consist of wet and dry detention basins, large pipes, and concrete structures. Recently, new practices of managing stormwater have begun to develop that place the focus on preserving and maintaining the natural hydrology within a watershed. Maintaining and replicating natural hydrology provides sustainable benefits that include reductions in pollutant and nutrient loading to existing watersheds, groundwater recharge, decreasing erosion, and lowering the burden on existing sewer and stormwater management infrastructure.

The new practice and understanding of stormwater management can be seen in large metropolitan areas in the United States such as Chicago, Los Angeles, and Seattle, as well as smaller municipalities and local communities (Newell, et al. 2012). In particular, the City of Chicago and surrounding area have recently developed codes and requirements that promote sustainable stormwater management for new developments within their jurisdiction. Examining the current trend in Chicago will

© ASCE 2014

provide information for further discourse and discussion of sustainable urban stormwater management on a national and global level.

This paper will examine the differing requirements for sustainable stormwater management in public and private developments. Upon review of the requirements, we will examine several case studies that implement sustainable stormwater management in both public and private projects. These case studies have several key components in common. First, stakeholder initiative is critical for the project's successful use of sustainable stormwater management. Regulating agencies and owners must be familiar with sustainable best management practices (SBMPs) and educated in their application. Second, stakeholder and design team collaboration is essential as all vested parties must understand the application of SBMPs and their maintenance. Finally, sound engineering practice and experience must be applied in the design and construction of SBMPs. Through sustainable stormwater management, several of the projects noted in this paper have achieved "zero" stormwater discharge for the 100 year recurrence interval storm event.

II. Stormwater Management for Developments on Private Property

The City of Chicago is located on the shores of Lake Michigan, one of the largest natural bodies of freshwater in the world. The City of Chicago and surrounding adjacent community have sought ways to minimize negative impacts to Lake Michigan and the rivers and streams that make up the Chicago, Calumet, and Lake Michigan watersheds (McConkey 2011). In particular, past occurrences of combined sewer overflows (CSO's) of untreated flood water into the Illinois River and Lake Michigan have played a large part in the need for stormwater management plans that reduce the volume of stormwater runoff prior to reaching the catchment area of the sewer system (Changnon 2010).

The City of Chicago and the Metropolitan Wastewater Reclamation District of Greater Chicago (MWRDGC) have spent considerable capital to implement a system of deep tunnels that detain stormwater during rain events that exceed the storage capacity of the sewer system under MWRDGC and City of Chicago jurisdiction. While these deep tunnels provide a large volume of temporary storage for stormwater, this infrastructure is not a means to an end when it comes to urban stormwater management (Daley 2012). In response to decreasing the probability of problematic consequences from large rainfall events, the City of Chicago and MWRDGC have recently updated their stormwater management requirements for new developments.

In the case of Chicago, in 2008 the City enacted a new stormwater management ordinance that provides a volume control requirement in addition to the rate control of stormwater. The intent of this requirement is to promote stormwater management design that can retain stormwater onsite rather than release to the City's combined storm and sanitary sewer network. The City has included in their current 2012 stormwater ordinance guidance on various sustainable best management practices

© ASCE 2014

(SBMPs) that can achieve the volume control requirement. These include bio swales, porous pavement, rain gardens, infiltration vaults, and planters that capture roof runoff (Daley 2012).

Similarly, the MWRDGC released a revised Watershed Management Ordinance (WMO) in May of 2014 that includes a volume control requirement. The new MWRDGC WMO requires new developments to capture and retain (to the extent possible) the first 1" of rainfall on a site (Meany 2014). The MWRDGC jurisdiction for stormwater management requirements generally includes all of Cook County, IL, with the exception of the City of Chicago.

During a rain event, the first flush of stormwater contains the most pollutant and nutrient load, hence the requirement of both the MWRDGC and the City of Chicago to retain and treat this volume of stormwater using a variety of SBMPs (Zellner et al. 2010). Both the MWRDGC and the City of Chicago stormwater management requirements cover a land area of approximately 945 square miles and include a population of approximately 5.2 million people (US Census Bureau 2014). The implementation of the volume control component for stormwater management can have a measurable positive impact on a watershed (Zellner et al. 2010), particularly given the large urban land area and population of major US cities.

III. Stormwater Management for Public Infrastructure

The new stormwater management requirements enacted by the City of Chicago and the MWRDGC contain specific requirements for developments with land disturbing activities on private property. Streetscape projects and typical roadway improvement projects must manage stormwater, but the requirements and scope of the improvements that typically utilize stormwater SBMPs is relatively low (Roy 2008). This may be a function of the limited available area within the public way that can be used by a stormwater SBMP, funding and budgetary concerns, lack of understanding, and unknown cost and benefit data (Roy 2008).

In the City of Chicago, public right of way (ROW) accounts for approximately 23% of the total land area of the City (Attarian, 2010). Most of this ROW is comprised of impervious paving, which in turn generates a larger volume of stormwater runoff than pervious and landscape areas, and increases the nutrient and pollutant loading in stormwater discharged to the sewer or waterway. As a result, large urban cities including Chicago have begun implementing SBMPs into streetscape and alley designs (Newell et al. 2012, Attarian 2010, Rehan 2012). In the case of Chicago, guidelines for green infrastructure in stormwater management are discussed in their "Complete Streets" guidelines (Emanuel 2013), and is built upon in the City's subsequent "Sustainable Urban Infrastructure" guidelines (Emanuel 2013). These guidelines serve as a map to identify goals and strategies for sustainable stormwater management in public projects in the City ROW.

© ASCE 2014

Similarly, the MWRDGC has included guidelines and performance criteria for SBMP installations in the right of way within their jurisdiction and drainage area. Specifically, the new MWRD WMO indicates that ROW improvements that create new impervious area greater than or equal to one acre must meet the volume control requirement (Meany 2014). The MWRD WMO does indicate that implementation of SBMPs to reduce stormwater runoff volume for projects in the ROW be implemented "where practical" (Meany 2014). This is similar to the City of Chicago guidelines for sustainable urban infrastructure in that it acknowledges the variable nature of projects within the ROW, and implementation of SBMPs is considered on an individual basis.

IV. Case Studies

In an effort to provide examples of implementation of SBMPs, we will examine several private and public projects completed in Chicago. It is the hope of the authors that providing project examples that implement SBMPs on a local scale will further discussion of their use on a regional and global scale, as well as provide documentation for the specific SBMP implemented. The authors have direct design and civil engineering experience on the case study projects noted in this section.

A. Benito Juarez Community Academy Addition

The Benito Juarez Community Academy (Benito Juarez School) resides in the Chicago neighborhood of Pilsen, southwest of the Chicago Loop. The Benito Juarez School is a Chicago Public School (CPS), and services an estimated 1,800 students. As part of a 2007 three story building addition to Benito Juarez School, a new soccer field, plaza, softball field, and landscape was completed in the site work for the project. The project was regulated to provide stormwater detention under the 2007 City of Chicago Stormwater Ordinance. At that time, the City of Chicago did not have a volume control requirement as discussed in the previous section.

In order to meet the rate control requirement of the stormwater ordinance for the Benito Juarez School Addition, two distinct SBMPs were implemented. First, the majority of the stormwater generated as part of the new addition was sent to permeable concrete unit pavers located in the plaza area adjacent to the new addition. In the event the stormwater volume exceeds the capacity of the engineered aggregate base below the permeable concrete unit paving, an overflow system was designed to send water to a bio swale constructed near the Cermak Rd. ROW (Figure 1). Stormwater runoff from the new building addition roof is also directed toward the bio swale, where the velocity of the stormwater runoff is decreased, and water is allowed to infiltrate into the existing soils.

© ASCE 2014

Figure 1: Benito Juarez School Project Map
(Aerial Image Courtesy of Google)

As part of the adjacent CDOT Cermak Rd. project, the sidewalk on the Cermak Rd. streetscape adjacent to the school was designed in conjunction with the bio swale. Aligning the bio swale and streetscape design and construction allowed both projects to create a shared space between the school and the roadway. Both projects were enhanced by this shared use and allowed the streetscape and school projects to meet their sustainable goals for stormwater management within the given space available for construction.

The stormwater management plan implemented on the Benito Juarez School project did not require a sewer connection for discharge of stormwater into the City's combined sewer system. By increasing the stormwater time of concentration and allowing water to infiltrate into the existing soils in the bio swale, the permeable pavers, and the sport field, the 100 year storm discharge volume was accommodated onsite.

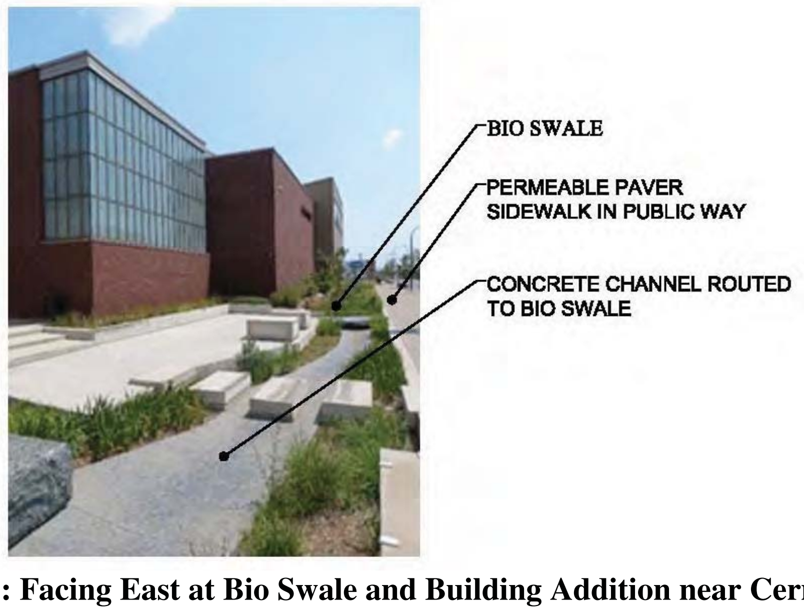


Figure 2: Facing East at Bio Swale and Building Addition near Cermak Rd.

© ASCE 2014

B. Powell Elementary School

The Powell Elementary School project is a new Chicago Public School built on an existing park adjacent to Lake Michigan in the Chicago South Shore neighborhood (Figure 3). The existing site consisted of relatively flat area, comprised almost exclusively of green space. As such, one of the main goals of the building and site work design was to maximize sustainability. The project was regulated to provide stormwater detention for the 100 year storm event as required under the 2008 City of Chicago Stormwater Ordinance. The 2008 stormwater requirements for the City of Chicago did require volume control of stormwater, and as such, selection of an SBMP was required to reduce the volume of water that was discharged from the site.

Stormwater management for the Powell Elementary School site consists primarily of the use of permeable concrete unit pavers (Figure 4). Runoff from the building and surrounding site is routed to a parking lot consisting of permeable concrete unit pavers supported by a 2'layer of open graded engineered backfill. This engineered aggregate base under the parking lot provides the required stormwater detention volume to meet the City of Chicago requirements for the 100 year recurrence interval storm event. Due to Powell Elementary School's close proximity to Lake Michigan, the existing soils found onsite generally consist of fine to medium sand. Hydraulic conductivity (k value) of the existing soil is high when compared to the hydraulic conductivity typically found in other areas of the City.

The geotechnical engineer for the project field tested and determined the k value of the existing soil prior to the design phase of the project. The calculated k value was found to be approximately 3.53×10^{-2} cm/s (approximately 50 in/hr). Final determination of the k value that was used on the project included consultation with the geotechnical engineer of record to determine the appropriate design k value that accounts for the potential effect of compaction of the existing soil associated with sub grade preparation and placement of engineered aggregate at the permeable paver parking area. The final k value used for design was approximately 7×10^{-3} cm/s (approximately10 in/hr).

Figure 3: Powell Elementary School Project Map

© ASCE 2014

Typical stormwater management design in Chicago requires a sewer connection to the existing City sewer for release of stormwater from a project site. In the case of Powell Elementary School, due to the existing soil hydraulic conductivity, a sewer connection was not required as the stormwater runoff volume from the site could be released into the existing soil below the permeable concrete unit paver parking lot. The excess volume required to balance the 100 year stormwater flow and the hydraulic conductivity of the soil was made up in storage in the engineered aggregate base course below the porous concrete unit pavers. Through this stormwater management design, the Powell Elementary School project did not discharge stormwater from the site up to the 100 year recurrence interval storm event.

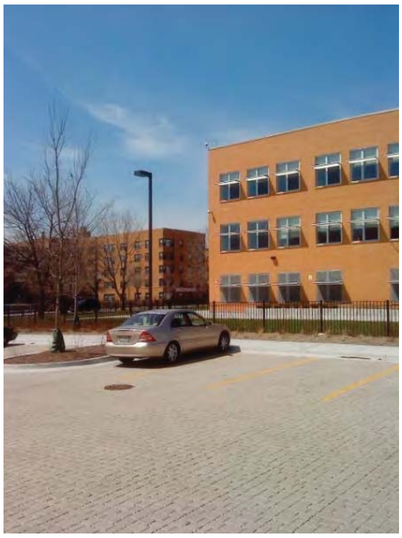


Figure 4: Permeable Paver Parking Lot at Powell Elementary School

C. Green Alleys

The City of Chicago and surrounding metropolitan area currently have initiatives for implementing SBMPs into their respective alley repaving projects (Daley 2007). In the case of Chicago, this was the first large city in the United States to implement and examine alleys for implementation of sustainable infrastructure (Newell 2012). This paper will examine two City of Chicago Green Alleys both in scope and application of stormwater SBMPs.

C.1 Belmont Green Alley

In 2009, the Chicago Department of Transportation (CDOT) collaborated to design improvements for an alley located one block south of Belmont Ave. between Harding Ave. and Springfield Ave. The alley was unimproved, and CDOT identified an opportunity to integrate sustainable stormwater management design to complete the alley improvements.

© ASCE 2014

The Belmont Green Alley was designed to be constructed of porous portland cement concrete (PCC). The porous PCC allows water to infiltrate through the paving surface, while providing a rigid pavement with a service life that met CDOT requirements. In the case of the Belmont Green Alley, the existing soils below the alley paving consisted of silty clay with a hydraulic conductivity of 4.8 x 10^{-4} cm/s (0.68 in/hr) . To maximize the infiltration of stormwater through the porous PCC and into the existing soils, the porous component of the pavement section of the Belmont Green Alley was maximized to extend the majority of the vehicular use area of the alley (Figure 5). While the hydraulic conductivity of the existing in situ soil was low, by maximizing infiltration area, a larger volume of stormwater runoff was infiltrated into the existing soil prior to overflow and release to the Chicago sewer.

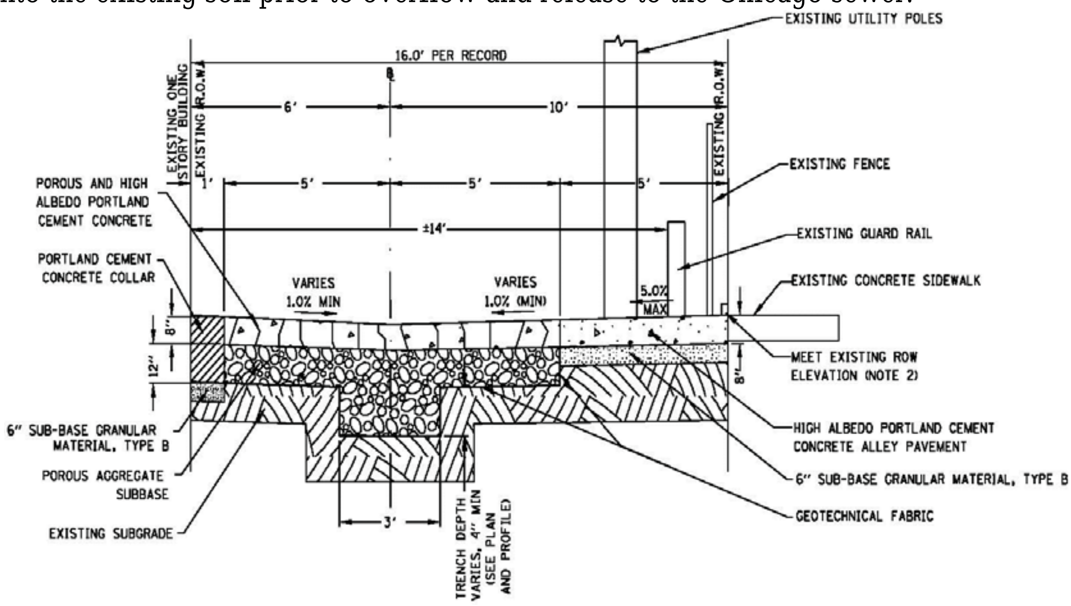


Figure 5: Belmont Green Alley Pavement Section

While the intent of the pavement section for the Belmont Green Alley was to maximize infiltration area from the pavement surface, consideration of the porous PCC paving mix design needed evaluation to ensure the paving met the requirements for repetitive vehicular use alley pavement experiences. As the permeability (void ratio) of the porous PCC increases, the compressive strength generally decreases (Schaefer et al. 2006). Based on CDOT's previous experience and research with implementation of porous PCC paving in green alley design, a mix design was chosen and specified for the project. In this case, a minimum 14-day compressive strength of 2,000 pounds per square inch (psi) was required, with a target void ratio of 22% (Daley 2009). The Belmont Green Alley project illustrates the multitude of variables that need consideration when designing porous paving systems for utilization as a SBMP.

C.2 Jones College Preparatory High School (Jones High School)

Jones High School is a new seven story Chicago Public School project located in Chicago's South Loop at the northwest intersection of Polk Street and State Street. As

© ASCE 2014

part of the school project, paving improvements were required to the adjacent alley due to its proximity to the proposed building structure. In addition, the building structure covers the site from lot line to lot line, and the new school building has a basement. Available area to meet the City of Chicago's stormwater management requirements was limited to within the building structure or the adjacent alley.

Through collaboration with CDOT and the Chicago Public Building Commission (PBC), the alley was identified as a resource to provide SBMP design and meet the Chicago stormwater management requirements (Figure 6). The 20.0' wide alley on the west side of the building was designed with a 4.0' center strip of porous PCC and aggregate base course. Stormwater from the adjacent Jones High School building was routed to the green alley, and the required stormwater detention was provided in the engineered aggregate base course below the alley pavement. In addition to providing rate control, the green alley provides reduction in volume by utilizing infiltration into the existing soils below the aggregate base course (Figure 7).

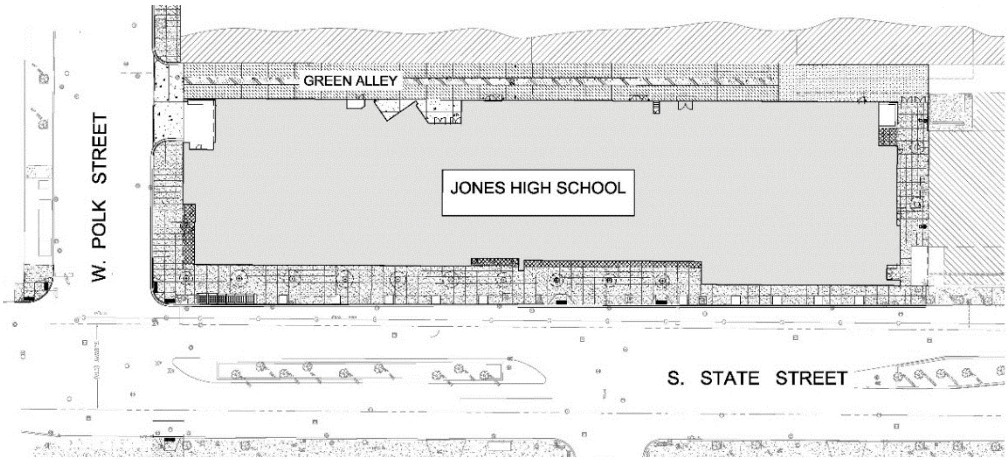


Figure 6: Jones High School Green Alley Location

The Green Alley design implemented on the Jones High School project is similar to the framework utilized in the Benito Juarez School project in that collaboration occurred between the manager of the development and the City to provide stormwater management infrastructure. By sharing the green alley infrastructure adjacent to the building, both CDOT and the PBC were able to achieve the project's functional and sustainable goals.

© ASCE 2014

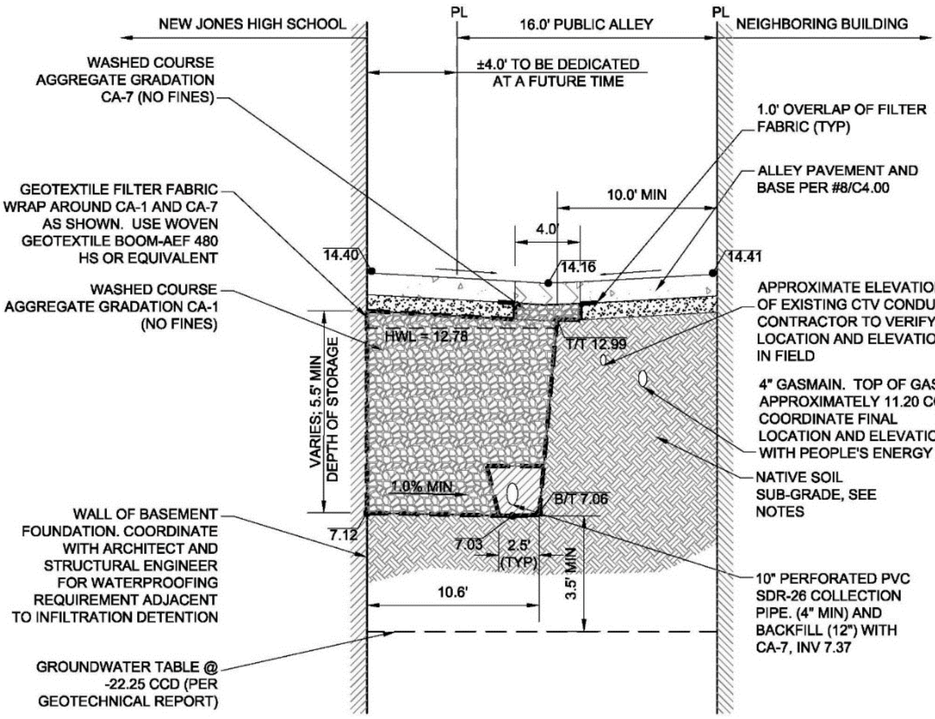


Figure 7: Jones High School Green Alley Section

V. Summary and Conclusions

The purpose of this paper is to outline local trends in sustainable stormwater management. By identifying specific local requirements for stormwater management and case studies of SBMP implementation, we provide information for discussion and application in other projects nationally and internationally. Providing specific engineering and design considerations for each SBMP mentioned is beyond the scope of this paper, however, by indicating cases that highlight their implementation, we can provide examples of projects that have specific successes in the use of sustainable stormwater best management practices.

The four case study projects described in this paper have several key components in common:

1) <u>Stakeholder Initiative:</u> These projects all involve stakeholders who promote and require sustainable practices for stormwater management as the benefits of implementing SBMPs are recognized. In the case of the Chicago area, the MWRDGC has just recently implemented new policies that require implementation of SBMPs for volume control of stormwater. By implementing the required use of SBMPs, MWRDGC is joining an increasingly large network of stakeholders who promote SBMP use through careful planning and awareness of the benefits they afford. Ultimately, as the number of stakeholders utilizing sustainable practices for stormwater management increases, the probability of

© ASCE 2014

other municipalities and governing agencies adopting the same requirements will increase.

2) Stakeholder and Design Team Collaboration: Collaboration of various agencies was a key component for the successful outcome of several of the projects discussed in this paper. Through collaboration, discussion and education can occur regarding sustainable stormwater best management practices, which can be a primary inducer of increased application of SBMPs (Roy 2008). As an increasing number of projects are completed that implement SBMPs, momentum can build for their use, as these projects can be used as examples to further the discourse of sustainable stormwater management and increase the probability of its expansion on a national and global scale. Implementation of SBMPs is typically on a case by case basis through evaluation of site and soil conditions. Through careful planning and coordination, projects that implement SBMPs have the potential to have positive impacts on existing watersheds, particularly if they can reach a "zero" discharge threshold and manage the majority of stormwater within the site rather than discharge to a sewer or waterway.
3) Sound Engineering Practice and Experience: Achieving a "zero" discharge of stormwater from a development or public improvement requires not only stakeholder approval and collaboration, but sound engineering practice. It is critical that all team members within a project work closely to investigate all possibilities to replicate natural hydrology and reduce stormwater runoff and pollutant load. Many times, engineers and designers are challenged to implement SBMPs within a project while not reducing the functionality of a site or the needs of the stakeholder. Engineers implementing SBMPs must be experts on a wide variety of technical aspects including geotechnical engineering, hydrology, pavement design, hydraulic analysis, and utility design. By examining specific projects that implement SBMPs, engineers and designers have a chance to review technical and design considerations for implementation in their own projects.

The successful implementation of SBMPs for the projects listed in this paper was completed through stakeholder acceptance of these practices, collaboration, and successful engineering practice. In addition to further investigation of these commonalities, the authors' believe closer examination of the social and economic benefits of sustainable stormwater best management practices is warranted. Many environmental benefits of SBMPs can be directly measured in the field. Meanwhile, social and economic benefits of SBMPs can be abstract, and measuring social and economic benefits of SBMPs must sometimes be completed without real market data (Wise et al. 2010). By researching and examining frameworks that include valuation of social and economic benefits of SBMPs (in addition to environmental), it may be possible to further the implementation of their use on a larger scale.

VI. Acknowledgements

The authors would like to thank all of our partners that have collaborated on the projects noted in this paper, of which there are too many to list. Specifically, we would like to thank the City of Chicago, Chicago Public Building Commission, Chicago Department of Transportation, Chicago Department of Water Management,

© ASCE 2014

Chicago Public Schools, the Metropolitan Water Reclamation District of Greater Chicago, and all the members of the design team for all projects mentioned in this paper.

VII. References

Attarian, Janet L. “Chicago’s Sustainable Streets Pilot Project”. *Presentation to the USEPA* (2010).

Changnon, Stanley A. “Stormwater Management for a Record Rainstorm at Chicago”. *Journal of Contemporary Water Research and Education* 146 (2010): 103-109.

Daley, Richard M. “The Chicago Green Alley Handbook: An Action Guide to Create A Greener, Environmentally Sustainable Chicago”. *City* (2007)

Daley, Richard M. “Chicago Department of Transportation Specification for Porous Portland Cement Concrete”. *City* (2009).

Emanuel, Rahm. "City of Chicago Stormwater Management Ordinance Manual." *City* (2012).

Emanuel, Rahm. “Complete Streets Chicago, Department of Transportation.” City (2012).

Emanuel, Rahm. “Sustainable Urban Infrastructure, Chicago Department of Transportation” *City* (2013).

McConkey, Sally, et al. “Major Watersheds of Illinois” *Illinois State Water Survey Map* (2011).

Meany, Kathleen Therese. “Article 5: Requirements for Stormwater Management”. *Metropolitan Water Reclamation District of Greater Chicago Technical Guidance Manual (Draft).* (2014).

Newell, Joshua P., et al. "Green Alley Programs: Planning for a Sustainable Urban Infrastructure?." *Cities* 31 (2013): 144-155.

Rehan, Reeman Mohammed. "Sustainable Streetscape as an Effective Tool in Sustainable Urban Design." *HBRC Journal* 9.2 (2013): 173-186.

Roy, Allison H., et al. "Impediments and Solutions to Sustainable, Watershed-Scale Urban Stormwater Management: Lessons from Australia and the United States." *Environmental Management* 42.2 (2008): 344-359.

Schaefer, Vernon R., et al. *Mix Design Development for Pervious Concrete in Cold Weather Climates*. No. Report No. 2006-01. (2006).

Wise, S., et al. "Integrating Valuation Methods to Recognize Green Infrastructure’s Multiple Benefits." *Center for Neighborhood Technology, April*. (2010).

U.S. Census Bureau. “State and County QuickFacts. Data derived from Population Estimates, American Community Survey, Census of Population and Housing, State and County Housing Unit Estimates, County Business Patterns, Non-Employer Statistics, Economic Census, Survey of Business Owners, Building Permits”. *Web Page http://quickfacts.census.gov/qfd/states/17/17031.html*. (2014).

Zellner, Moira, et al. “Using Green Infrastructure to Manage Urban Stormwater Quality: A Review of Selected Practices and State Programs”. *Illinois Environmental Protection Agency*. (2010).

© ASCE 2014

Evaluation of Sustainable Infrastructure: Development Context Matters

M.B. Reiner, Ph.D., P.E.[1], S. Fisher, Ph.D., P.E.[2], and J. Sperling, Ph.D.[3]

[1] Non Sequitur, LLC, 6948 Howell Street, Arvada, CO 80004; PH. (303) 596-1401; email: reiner@nsequitur.com
[2] Tetra Tech, 216 16th St., Ste 1500, Denver, CO 80202-5129; PH. (303) 312-8849; email: stephen.fisher@tetratech.com
[3] National Center for Atmospheric Research (NCAR) Urban Futures (RAL), P.O. Box 3000, Boulder, CO 80307; PH. (303) 497-8422; email: joshuabsperling@gmail.com

ABSTRACT

If infrastructure is considered the basic physical and organizational structure needed for the operation of a society, how will the rapidly urbanizing centers in the developing world, many of which have large informal communities (i.e., slums), provide it? Various tools exist that assist engineers in the design and evaluation of sustainable project features, but innovation and long-term acceptance of the systems are lost if the unique cultural characteristics and resource constraints are not used as a refractive lens prior to project considerations. In this paper, a framework is presented within the context of cultural and resource constraints to assist the successful adaptation and application of existing sustainable infrastructure evaluation tools. The framework recognizes that an individual project shares space in a hierarchical spectrum of development unique to each city, characterized by multiple influences and motivations at different scales within social, natural, and built systems.

Setting the Context of Sustainable Infrastructure Projects in Urbanizing Areas

The 13 most-populated urban areas in less developed regions experienced an annual average growth of 2.3% between 1990 and 2011 (WUP, 2011). For Delhi, India (a case study in this paper and one of the top 5 fastest growing cities in the world) with an observed and expected average annual growth rate of 2.67%, between 2011 through 2025, the current 18M population could double within 26 years, (Berkowitz, 2013). Informal communities have either absorbed urban migration or propagated to accommodate it, and this growth has often outpaced local governments' ability to comprehensively provide access to water supply, sanitation, and affordable and reliable energy (WHO, 2010). It should be recognized that, inside the geographic boundary of a developing city, a wide spectrum of types and condition of infrastructure have evolved over decades under the influence of, for example, revenues, governance, allocation of resources, demographic shifts, etc. (UNHCS/Habitat, 2000). In addition, housing in informal communities has limited or no basic utility services such as water, sewerage, and electricity.

Although development motives vary and outcomes may not be socially equitable, infrastructure generally meets the most basic levels of physiological, social, and economic needs of a society that foster resiliency and social stability. In order to

© ASCE 2014

ensure desired outcomes (e.g., improved health, economic activity, and resilience) a custom framework for implementing infrastructure may be employed that builds on a compendium of data that defines the unique social systems, expectations, constraints, and social acceptance of infrastructure. As these discussions preclude the *business-as-normal* approach to engineering projects, engineers must be at the table during initial planning and participate in the development of a foundation of contextual data.

Given this emerging context, this paper suggests development of a **c**omprehensive **r**esilient **i**nfrastructure **s**ystems **p**lanning (CRISP) framework that includes understanding the unique resource challenges and opportunities within diverse urban systems, including; socio-cultural, economic, governance, environment, and infrastructure systems to help inform project development, evaluation efforts for multiple defined goals (e.g. health, jobs, resilience, etc.) and stakeholder engagement processes and deliberations. As stakeholder engagement and sustainability assessment (SA) tools are well-documented at the project level, and many of the topics in Figure 1 are commonly performed before implementing large-scale projects, this paper discusses several unique aspects of a CRISP framework (Figure 1).

Foundational for developing the unique constraints and cultural narrative of the city are data collected in the "Systems Evaluation and Local Context" phase, prior to implementing projects. The baseline information, community resource inventories, and socioeconomic studies (discussed further in the Kigali, Rwanda case study) provide the unique cultural and resource 'lens' that provides its own unique refractive signature for approaching individual projects within sector systems, social, political, and economic contexts, and service delivery goals and expectations.

© ASCE 2014

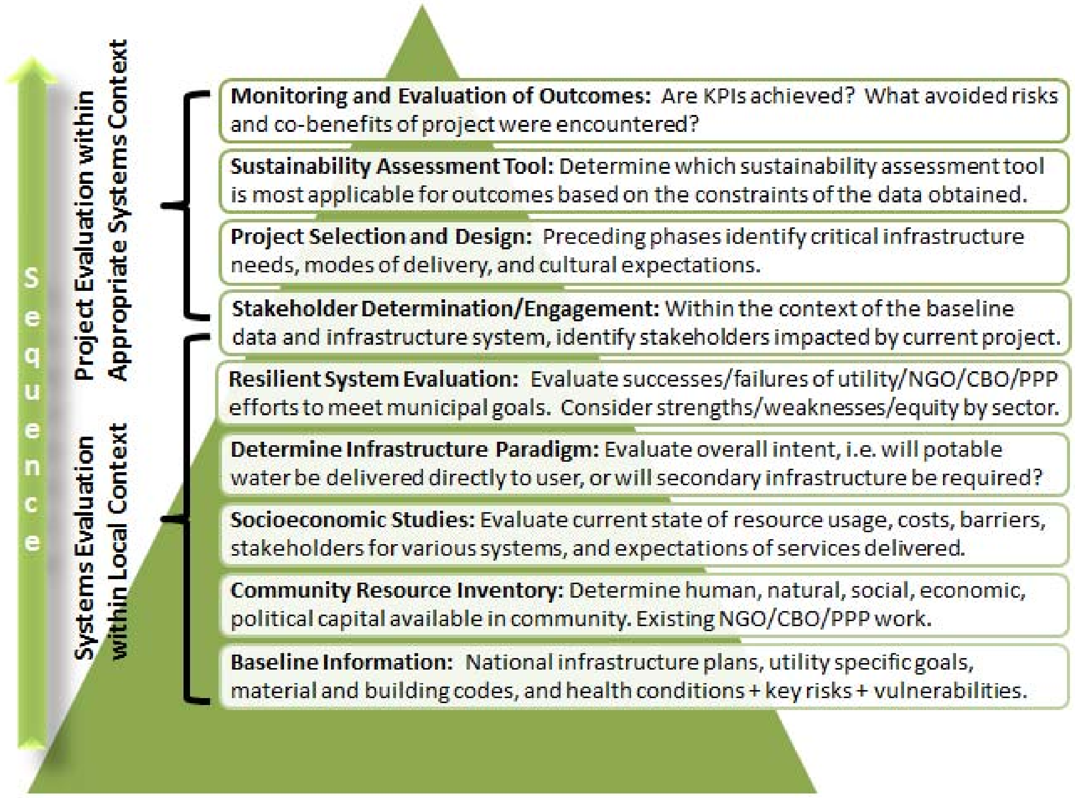


Figure 1: A CRISP Framework for Infrastructure Projects

Resilient Infrastructure Systems Paradigms

The interesting juxtaposition of various types of infrastructure within a developing municipality provides an opportunity to better understand the potential for innovation as neighborhoods may even be thriving, despite various levels of infrastructure service and quality. Consider the following paradigms:

- *Humanitarian (or informal)* infrastructure (characterized by point-of-use appropriate technologies and a strong emphasis on the underserved, marginalized, and disenfranchised) is typically used in the unplanned communities that are 'disconnected' from the centralized planning schemes,
- *Formal* infrastructure (characterized by larger, centralized treatment/production and distribution systems). This paradigm should be characterized by the quality and reliability of services delivered as follows:
    - *Comprehensive*: where all services are provided and quality and reliability meets expectations, and
    - *Failed Comprehensive*: where centralized infrastructure services do not meet end-user expectations which results in ownership of secondary infrastructure, e.g. ceramic water filters, diesel generators; and;

© ASCE 2014

- *Hybrid* infrastructure maintained by NGOs/PPP/CBOs/social entrepreneurs outside of the utility that have elements of formal and humanitarian infrastructure.

Characterizing and geographically mapping each of the existing infrastructure paradigms provides information regarding current expectations of access, barriers, innovations, costs, and reliability of existing service levels. This important step also recognizes the success or failure of infrastructure that is a result of ad-hoc and informal community processes. Much can be learned from informal infrastructure delivery that performs well; it is possible for formally planned and executed infrastructure to fail spectacularly by comparison (i.e., 'failed comprehensive').

This infrastructure assessment, within the constraints of the baseline information, community resource inventories, and socioeconomic studies (discussed further in the Kigali, Rwanda case study), provide a cultural and resource 'lens' that provides its own unique refractive signature for systems evaluation. Once these foundational phases are completed, design and execution of the successful project is possible. The engineer that has not been a part of the foundational phases is highly constrained and is at risk of designing inappropriate infrastructure, even if he or she is using appropriate SA tools, two of which are described briefly below.

Current Sustainability Tools and Developing Key Performance Indicators

In recent years, there have been significant developments in creating tools for assessing the sustainability of infrastructure. These have largely been targeted at the project level. Because project-level SA tools are not designed to address the larger systems of which they are a part (Mulligan et al., 2011), a SA must build on the systems evaluation step and provide a guideline for defining success within an infrastructure master plan and system-level key performance indicators (KPI). KPIs must define and measure system-level expectations that transcend the project level. For example, even with individual household water connections, decades of cultural norms of being skeptical of the quality of water may lead to the majority of residents purchasing bottled water, i.e. creating a failed comprehensive paradigm for water delivery. While in unplanned communities, 'access to water' may be defined as 'within 30 minutes to good quality water' without guarantees of low-cost or reliability (NCWSC/AWSB, 2009). The difference in definitions and expectations creates distinct drivers for all infrastructure services and provides challenges when selecting a common SA for an urban master plan.

In the master planning context, a recognized SA tool is helpful for creating a common definition of 'success' for infrastructure delivery between stakeholders, the client, and engineering/planning team. But, the SA is now viewed through the boundaries and expectations of the existing cultural narrative of the city and projects are approached from the understanding of how systems work together and the constraints faced. Two widely-known SA tools with a well-defined set of KPIs for evaluating new infrastructure projects for planned and unplanned communities are Envision and ASPIRE, respectively.

© ASCE 2014

Envision (developed by the Institute for Sustainable Infrastructure) emerged specifically to rate project sustainability of horizontal infrastructure in the U.S. context. The key drivers of this SA tool are performance contribution and pathway contribution. Performance contribution is the efficiency or effectiveness of the project whereby project teams seek out all reasonable opportunities to improve sustainable performance by raising the bar in one or more dimensions of performance, i.e., "Are we doing the project right?" Pathway contribution considers how the project aligns with overall community needs and enhances quality of life, i.e., "Are we doing the right project?" Currently, this tool is project / site specific (in North America), without explicitly addressing health or synergies with other city resiliency goals.

ASPIRE (developed jointly by Arup and Engineers Against Poverty) was designed primarily for application in the developing country context, recognizing the important role infrastructure plays in improving health, reducing poverty, and achieving U.N. Millennium Development Goals (MDG). Poverty alleviation is derived through, for example, access to services, public health, culture, and stakeholder participation. Two additional themes addressed - vulnerability and population - include metrics for conflict, exposure to natural hazards, and displacement. This tool evolved as a modification of the existing proven SA tool, SPeAR, bringing together a large number of indicators (including from the UK government, UNEP, Global Reporting Initiative, etc.) to assess total impact of a project on the environment, natural resources, and socio-economic conditions. Currently, a limitation to Aspire is a limited assessment of current and future direct/indirect health outcomes related to infrastructure. This is discussed further in the next section.

Filling a Gap with CRISP – Linking Public Health, Infrastructure and SA Tools

In rapidly urbanizing settings, infrastructures and related environmental conditions (e.g. air and water quality) can be quite poor, resulting in numerous adverse health outcomes: including heart disease and heart attacks, asthma, diarrhea, cancer, transport accidents, diabetes, tuberculosis, and so on. Accompanying rapid urbanization has been even faster growth in populations residing in slums, leaving these marginalized populations increasingly exposed / susceptible to diverse hazards. Few current sustainability assessment (SA) tools adequately address infrastructure and health linkages within this context.

Two tools discussed in this paper, Envision and ASPIRE, were developed with differing motives, and, as a result, the approach to considering the link between public health and infrastructure is dealt with very differently. For Envision, the primary metrics are safety of materials and technologies (QL2.1), construction noise (QL2.2), and reducing dependency on motorized vehicles (QL2.4, QL2.5). ASPIRE recognizes a contribution to public health by providing access to clinics or through education. However, in recent years, as rapid population growth has outpaced capacity to provide basic infrastructure services, multiple urban hazards and related health risks have grown in significance. Urban outdoor air pollution causes 1.3

© ASCE 2014

million deaths worldwide, indoor air pollution from improperly ventilated cook stoves burning solid fuels is responsible for 1.6 million deaths (2.6% of all deaths) worldwide (WHO,2011), 3.5 million more deaths are related to water sanitation and hygiene (WHO, 2008), and transportation crashes account for 1.2 million additional deaths. Therefore, establishing health outcomes based on baseline data and quantifying infrastructure-related health risks / benefits via different upgrades are critical to future assessment of current 'informal' and 'failed comprehensive' infrastructure systems.

The list of associations between health risks and infrastructure in cities is quite long, with many direct and indirect benefits of urban infrastructure to health as can be seen in Table 1 (Sperling and Ramaswami, 2013). By assessing baseline health conditions related to multiple infrastructures, efforts can be made as part of CRISP planning processes to include more defined health KPIs, such as premature mortality, illness, and loss of productive livelihoods and education.

Table 1. Infrastructure-Related Benefits / Risks and Linkages to Health Outcomes.

Infrastructure Sector	Literature Review of Health Benefits (Direct and Indirect)	Literature Review of Health Risks (Direct and Indirect)
Transport	Access to work, school, & essential health services (Killoran et al., 2011; Babinard & Roberts, 2006); wealth, job creation, economic development (Mohan, 2004)	Accidents (WHO, 2004); transport-related urban outdoor air pollution affecting asthma exacerbation, acute & chronic bronchitis, respiratory / cardiovascular illness, & lung cancer (Samet, 2000); lack of mobility as causal factor in maternal & neonatal mortality (Molesworth, 2006)
Energy	Enables improved standards of living (Pasternak, 2000), extended hours & expanded services for hospitals (Hess, 2011; Schwartz et al., 2011); enables cooking, boiling water, space heating, cooling; electricity; transport enabling access to livelihoods; social networks; industrial production; & communication (Wilkinson, 2007; Saatkamp et al., 2000; McMichael, 1994)	Outdoor and indoor air pollution (Listorti, 2004; IEA, 2010), injury risks, and industrial hazards (Venkataraman et al., 2010); cardiovascular disease; respiratory disease; bronchitis; asthma; and eye infections (Kammen, 2011)
Water Supply & Sanitation	Reduces waterborne illnesses and prevent spread of animal-borne disease pathogens (Butala, 2010); reduces infant mortality (UNW-DPAC, 2011) & mosquito-related illnesses (Gunther, 2011)	Diarrhea (Montgomery, 2007), schistosomiasis, intestinal helminths; trachoma; trypanosomiasis (Eisenburg et al., 2001); malnutrition (Gleick, 2002); cholera; typhoid (WQHC, 1995); lung, bladder & skin cancer (Smith, 2000)
Hazardous Waste Management	Protects water, air, & soil by promoting proper storage & disposal of toxic waste (Guerriero, 2009)	Toxic chemicals and waste affect airway diseases and brain, lung, & gastrointestinal cancer (Rushton, 2003)

Case Studies

Two development case studies are presented for Kigali, Rwanda and Delhi, India. Both contain examples of the systems evaluation phase of the CRISP framework with Kigali focusing more of social and natural resource constraints and innovations and Delhi focused more on determining direct/indirect health outcomes of infrastructure planning. While neither of the previously discussed SA tools were used in these case studies, primary points for informing future master planning and infrastructure design efforts are 1) understanding potential innovations within the context of resource challenges and opportunities of each city, and 2) SA tools need to explore direct/indirect public health KPIs associated with infrastructures and infrastructure-related environmental factors (e.g. air and water quality, GHG emissions, and extreme weather events).

Infrastructure Master Planning for Kigali, Rwanda

Infrastructure baseline assessment and sustainable future scenarios were developed for Kigali, Rwanda (Oz Architecture, 2006). Before developing specific infrastructure systems strategies, the cultural and resource constraints needed to be answered. These were: 1) what energy source will be the primary driver for Rwanda's infrastructure over generations to come; and 2) how will infrastructure services be delivered to current and future informal communities that compose approximately 80% of Kigali. Another critical theme was to consider the amount of lost human capital and education potential by residents focusing on subsistence activities rather than higher level activities, such as participation as a productive worker-citizen (Maslow, 1943).

Rwanda's energy portfolio was/is heavily dependent on fossil fuels imports from east African refineries. Without rail and efficient highways, the tenuous importation of fuel was considered a natural resource constraint to designing long-term and low-carbon infrastructure solutions. In the "land of 1,000 hills", gravity and potential energy were considered as a primary fuel would drive a portion of our infrastructure model. This was accomplished by declaring watershed boundaries within Kigali to contain "Environmental Treatment Zones" (ETZ) as scalable units of distributed infrastructure systems (OZ Architecture, 2007). On the macro scale, the ETZ provided the foundation for providing a more comprehensive approach to integrating infrastructure at the municipal level by collectively identifying strategic points for treatment before contaminants moved downstream.

In order to understand the baseline for answering the second question, a socio-economic study of the existing infrastructure and service level in informal communities within Kigali yielded the following statistics for cells within the Gitega, Kacyiru, Rusororo, and Muhima sectors, representing about 450 households.

- **Water:** Approximately 70% relied on water delivered by the local utility (Electrogaz, currently called EWSA), located an average of 278 m from their house, at an average cost of $0.04 for 20 L. However, as service at these tap stands was not regular (in some cases, the water was on for only 1 day per

© ASCE 2014

week) and the distance to secondary water sources was 1.9 km, the average consumption was 15.2 liters per day per capita, well below minimum WHO and MDG standards for long-term survival.

- **Sanitation:** Although there was a centralized municipal solid waste (MSW) disposal site, collection of solid waste could not be performed by the City as there was not road access for many of the residents of these communities. Rather, a public-private partnership was developed with local women's groups to collect, sort, recycle, and dispose of the waste at an average monthly cost per household of $1.60 with an average of 3.8 families combining their resources, and waste, to pay for this service. Wastewater sanitation was essentially non-existent other than simple disposal in pit latrines with an average of 4.0 families (average of 4.8 persons per family) using one pit latrine.
- **Energy:** The average household spent approximately 5 percent on electricity. This varied from approximately 3 to 10 percent, depending on the neighborhood, with poorer neighborhoods paying proportionately higher percentages for electricity. At the time, roughly only four percent of the Rwandan population was connected to the utility electric grid. Consequently, the majority of the Rwandan populace utilized other energy sources to meet their needs, cooking energy being the largest. In most cases, the fuel of choice was wood, peat and charcoal upon which an estimated 85 to 90 percent of Rwandans relied.
- **Housing:** The National Policy of the Habitat in Rwanda, developed by the Ministry of Infrastructure (MININFRA) declared that the primary constraints to sustainable construction were the continued importation of construction materials and a lack of standards for low-cost, native building materials (MININFRA, 2004). The building code (Strategy 3.1. "Promotion of the production and use of local materials of construction") called for all houses to be constructed of "durable local materials". However, the socio-economic study found that approximately 90% of households were not constructed with materials that would be considered as "durable".

Delivering centralized, or formal, services to individual households in the existing and densely populated informal communities, was not possible. Therefore, the strategy was divided into macro services delivered on a watershed basis and those services that could be generated onsite at the individual household with informal type of infrastructure.

On the macro level, the ETZ allowed for many synergistic land uses and enterprises such as municipal solid waste collection, storm water treatment, flood control, wetland management, wastewater treatment, composting, sorting of recyclables, biogas generation and processing, briquetting of dry organics, staging area for organic waste collection, staging area for sale or transfer of organic wastes or compost, and staging areas for transfer of solid waste and sale or transfer of recyclables. Thereby the conceptual master plan fully integrated formal and informal engineering approaches.

© ASCE 2014

The authors believe that conventional master planning, without such engineering approaches, would have resulted in segregated areas for these activities, squandering the potential for synergy and making many social and economic activities for some demographic classes unviable. At the individual household level, delivery of services to end-users, to at least meet partial needs, of water, energy, and sanitation through informal infrastructure integrated into the individual housing first depended on successfully answering the low-cost "durability" question. Workshops were developed for stakeholder engagement to discuss the durability and constructability of stabilized compressed earth blocks (SCEBs) to provide a low-cost and attractive low-cost housing solution. Upon successfully developing acceptable SCEBs, the informal infrastructure was integrated into an actual low-cost model (constructed as part of the conceptual master plan efforts by a partnership of the City of Kigali, German Development Service (DED), Engineers Without Borders-USA (EWB-USA), and the German Embassy in Rwanda) that allowed for capture of rainwater, bio-digester for sanitation, and solar panels (Ilberg and Rollins, 2007).

This low-cost model represented a working model of informal infrastructure delivery within the informal areas of Kigali and was replicated with over 250 units in the Batsinda Sector of Kigali and was estimated to provide approximately 60% of water needs, wastewater disposal, and electricity (for those that chose the solar option) utilizing humanitarian engineering approaches.

Infrastructure Characterization and Priorities in Delhi, India

Currently, 55% of households in the National Capital Territory of Delhi, India live within 500 meters of roads with high levels of air pollution (putting residents at risk of cardiac and respiratory problems), 16% of households in Delhi lack access to drinking water taps (putting residents at risk of waterborne illnesses), 6% lack access to latrines, and 8% are using wood, dung and charcoal for cooking. In addition, more than one third of urban inhabitants in Delhi live in informal communities where populations are often at higher risk due to weaker structures, less safe locations, and the inability of infrastructure to withstand extreme weather events related to heat and flooding if poorly designed / constructed.

Local field-work activities in 2012-2013 included three main objectives, including, assessing: 1. the current social, economic, environment, infrastructure, and governance systems at household, neighborhood and city scales; 2. household experiences with access to urgent healthcare and different inconveniences related inadequate infrastructures, pollution and extreme weather events; and 3. how current infrastructure and environmental conditions shape both human development (e.g. health) and sustainable development (e.g. environment) aspirations in diverse neighborhoods within Asian cities. An overview of methods and results specific to the links between health and infrastructures, followed by findings on local priorities are described next. First, an exploration of whole-population baseline data regarding mortality, under-five years mortality,

© ASCE 2014

morbidity, life expectancy, and hospitalization statistics were analyzed and where possible correlated with environmental conditions and provision and upgrading of specific infrastructures (note: this includes current conditions across seven infrastructure sectors). Then, infrastructure conditions were characterized in neighborhoods where future sustainability priorities were also assessed demonstrating the new opportunities for focusing CRISP efforts and development actions especially within Delhi and other Asian cities. A summary of key results on infrastructure-health associations are below:

- Mortality data along with a survey of local expert opinion indicated up to 19 percent of all recorded deaths in Delhi may be infrastructure related (Sperling & Ramaswami, 2013).
- Under-five mortality rates for urban India, including Delhi, and seven other cities were found to be greater than 8 times higher for poor/low literacy with absence of multiple services within the household (e.g., toilets, taps and clean fuels) compared to those with services: 34.9 child deaths per 1000 births versus 4.0 child deaths per 1000 births (Sperling & Ramaswami, 2015 (forthcoming)).
- Higher levels of total sick days to total person-days for those neighborhoods with less high quality infrastructure provisions (this included infrastructure indicators such as access to piped water into dwelling, travel > 30 minutes for water supply, housing type, electricity access, use of solid fuels or LPG/natural gas for cooking, access to healthy food supply including fruit in diet, a motor vehicle, toilet facility in home, waste disposal services, underground closed drainage, and to parks and open space) (Sperling, 2014).
- Higher levels of hospitalization in days following high air pollution episodes (Sperling, 2014).

In terms of cultural expectations, access to basic infrastructure services, such as water supply, drainage, and affordable electricity was often found to be a higher priority than outdoor and indoor air pollution or extreme weather events such as heat and drought, rain and flooding. The findings demonstrated how households deprived of infrastructure provisions will prioritize needs and services. In addition, households would often vary in their ability to cope with and respond to various stresses due to infrastructure, environment, and extreme weather – typically with detriment to the health of household members (illnesses including and related to typhoid, diarrhea / abdomen pain and vomiting, jaundice, dengue, malnutrition, pregnancy/delivery that are much less common in cities of what is currently known as the developed world). An important lesson from this work is that the CRISP framework would be capable of considering the diverse characteristics of infrastructure conditions, health risks, and local priorities by neighborhoods (i.e. it is often the case that 'not all slums are equal'), prior to design and execution and SA evaluation of infrastructure.

CONCLUSIONS

© ASCE 2014

This paper promotes the development of a vision and use of a framework to implement sustainable infrastructure projects. The vision is determined by the definition of 'success' for a city and its stakeholders, based on the cultural narrative of constraints and potential innovations. The framework places infrastructure projects within the spectrum of development motives and priorities. The CRISP framework attempts to identify the potentials of the city by understanding its cultural expectations and constraints prior to systems planning and appropriate infrastructure design and application of SA tools. An exciting opportunity lies in the ability of engineers, planners, policy actors and various institutions, to more effectively address the nexus of informal and formal infrastructure systems that build resilience and are comprehensive in considering economy, environment, and equity (particularly in terms of health risks and outcomes). While further work would be useful to integrate the CRISP framework across the built environment, natural systems, and socio-political systems, there are several key lessons from this study that can help inform future research and action:

- Innovation only occurs by developing the unique context of the urban environment. While using an SA tool is useful to develop some KPIs, many social and natural capital constraints that drive innovation may be overlooked;
- SA tools can be useful in both preliminary master planning and design/construction phases for evaluating the common denominators and pros and cons of both formal and informal communities; and
- Future work can improve upon baseline information gathering, community resource inventories, **direct and indirect health outcomes,** and socio-economic characterization.

© ASCE 2014

REFERENCES

AusAid. (2011). "*Sustainable economic development Transport, water, urban, energy and communications infrastructure*," November.

Babinard, J. and P. Roberts. (2006). *Maternal and child mortality development goals: what can the transport sector do?* The World Bank. Accessed online May 2011: http://www.eldis.org/index.cfm?objectId=12FF2014-F8B6-EF21-2FC73C39FBAA7E93.

Berkowitz, M. (2013). "The Five Fastest Growing Cities." Rockefeller Foundation. Accessed online June 2014: http://www.rockefellerfoundation.org/blog/five-fastest-growing-cities.

Butala, N., VanRooyen, M., and Patal, R. (2010). "Improved health outcomes in urban slums through infrastructure upgrading." *Social Science & Medicine*. 71 pp. 935-940.

Eisenburg, J. N. S.; Bartram, J.; Hunter, P. R. (2010) "A Public Health Perspective for Establishing Water-Related Guidelines and Standards. In *Water Quality Guidelines, Standards, and Health: Assessment of Risk and Risk Management for Water-Related Infectious Disease*; WHO, Geneva, pp 229–256.

Gleick, P. H. (2000). *Dirty Water: Estimated Deaths from Water-Related Diseases 2000–2020*. Pacific Institute, Oakland, California.

Guerriero, C. and Cairns, J. (2009). "The potential monetary benefits of reclaiming hazardous waste sites in the Campania region: an economic evaluation." *Environmental Health*. 8:28.

Gunther, I. and G. Fink. (2011). "Water and Sanitation to Reduce Child Mortality: the Impact and Cost of Water and Sanitation Infrastructure." Research Working Paper 5618, The World Bank: Development Economics Prospects Group.

Hess, J.J., Bednarz, D., Bae, J.Y., and Pierce, J. (2011) "Petroleum and Health Care: Evaluating and Managing Health Care's Vulnerability to Petroleum Supply Shifts." *American Journal of Public Health*. doi: 10.2105/AJPH.2011.300233.

International Energy Agency (IEA). (2011). "Implication of Energy Poverty on Health & Environment." Accessed May 2011: http://www.iea.org/weo/implication.asp.

Ilberg, A., and Rollins, C. (2007). *Low Cost House: Construction Manual*. Kigali, Rwanda.

Kammen, D. et al. (2011). *Household Cookstoves, Environment, Health, and Climate Change: A New Look at an Old Problem*. The Environment Department (Climate Change), The World Bank, New York.

Killoran, A., Doyle, N., Waller, S., Wohlgemuth, C., and Crombie, H. (2006). *Transport Interventions Promoting Safe Cycling and Walking*. National Institute for Health and Clinical Excellence. Accessed March, 2011: http://www.nice.org.uk.

Listorti, J. and Doumani, F. (2004). *Energy and Environmental Health: A Literature Review and Recommendations*. Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP).

© ASCE 2014

Maslow, A.H. (1943). "A Theory of Human Motivation." *Psychological Review*. 50(4), 370–96.

McMichael, A, Woodward, A. and Leeuwen, R. (1994). *The Impact of Energy Use in Industrialised Countries upon Global Population Health*. *Medicine & Global Survival*. Vol. 1, No. 1.

Ministry of Infrastructure (MININFRA) (2004). *National Policy of the Habitat in Rwanda*." Republic of Rwanda, Kigali.

Mohan, D. (2004)."The Road Ahead: Traffic Injuries and Fatalities in India", New Delhi, India. Accessed online May 2011: http://tripp.iitd.ernet.in/publications/paper/safety/road_ahead.pdf.

Molesworth, K. (2006). *Mobility and Health: Impact of Transport Provision on Direct and Indirect Determinants of Access to Health Services*. Swiss Centre for International Health, Swiss Tropical Institute.

Montgomery, M. and Elimelech, M. (2007). "Water And Sanitation in Developing Countries: Including Health in the Equation." *Environmental Science & Technology*. 41(1)17-24.

Mulligan, Tuzzolo, Stigge and Guthrie. (2011). "Tailored sustainability assessment for urban masterplanning," *Urban Design and Planning*. 164(DP2).

Nairobi City Water and Sewerage Company (NCWSC) and Athi Water Services Board (AWSB). (2009). *Strategic Guidelines for Improving Water and Sanitation Services in Nairobi's Informal Settlements*.

OZ Architecture. (2006). *Existing Conditions Report: Kigali, Rwanda*. Denver, Colorado.

OZ Architecture. (2007). *Conceptual Master Plan Report: Kigali, Rwanda*. Denver, Colorado.

Pasternak, A. (2000). *Global Energy Futures and Human Development: A Framework for Analysis*. US Department of Energy, Lawrence Livermore National Laboratory.

Rockefeller Foundation. (2014). "The Five Fastest Growing Cities." Accessed June, 2014: http://www.rockefellerfoundation.org/blog/five-fastest-growing-cities.

Rushton L. (2003). "Health hazards and waste management." *British Medical Bulletin*. (68)1:183-197.

Saatkamp, B., Masera, O., and Kammen, D. (2000). "Energy and health transitions in development: fuel use, stove technology, and morbidity in Jarácuaro, México." *Energy for Sustainable Development*. (4)2. August.

Samet, J.M., Zeger, S.L., Dominici, F., et al. (2000). "The National Morbidity, Mortality, and Air Pollution Study. Part II: Morbidity and mortality from air pollution in the United States." *Research Report Health Effects Institute*. 94:5-70.

Schwartz, B., Parker, C., Hess, J.J., and Frumkin, H. (2011). "Public Health and Medicine in an Age of Energy Scarcity: The Case of Petroleum." *American Journal of Public Health*. doi 10.2105/AJPH.2010.205187.

Smith, A., Lingas, E., and Rahman, M. (2000). "Contamination of drinking-water by arsenic in Bangladesh: a public health emergency." *Bulletin of the World Health Organization*. 78(9).

© ASCE 2014

Sperling, J. (2014). Exploring the Nexus of Infrastructures, Environment and Health in Indian Cities: Integrating Multiple Infrastructures and Social Factors with Health Risks. Ph.D Thesis: University of Colorado.

Sperling, J. and Ramaswami, A. (2013). "Exploring Health Outcomes as a Motivator for Low-Carbon City Development: Implications for Infrastructure Interventions in Asian Cities", *Habitat International*. 37:113-23.

United Nations (UN) Human Settlements Programme. (2000). "Decentralization and Urban Infrastructure Management Capacity (Final Draft)", Background Paper Prepared for *The Third Global Report on Human Settlements* - UNHCS/Habitat, The Center for Urban Development Studies, Harvard University Graduate School of Design, August.

UN. Water Decade Programme on Advocacy and Communication (UNW-DPAC). (2010). *Water and Cities: Facts and Figures*. Accessed online May 2100: http://www.un.org/waterforlifedecade/swm_cities_zaragoza_2010/pdf/facts_and_figures_long_final_eng.pdf.

UN. (2011). *World Urbanization Prospects: The 2011 Revision*. Department of Economic and Social Affairs, Population Division. Working Paper No. ESA/P/WP/200.

Venkataraman, C., Sagar, A.D., Habib, G., Lam, N. Smith, K.R. (2010). "The Indian National Initiative for Advanced Biomass Cookstoves: The Benefits of Clean Combustion." *Energy for Sustainable Development*. 14 pp. 63–72.

Wilkinson, P., Smith, K., Joffe, M., and Haines, A. (2007). "A Global Perspective on Energy: Health Effects and Injustices." *The Lancet*.

World Health Organization (WHO). (2008). *Safer water, better health: Costs, benefits, and sustainability of interventions to protect and promote health.* Accessed July, 2011: http://www.who.int/quantifying_ehimpacts/publications/saferwater/en/index.html

WHO. (2010). "Hidden Cities: Unmasking and Overcoming Health Inequities in Urban Settings." UN Human Settlements Programme, Kobe, Japan.

WHO. (2004). *World report on road traffic injury prevention*. Accessed March 2011: http://www.who.int/violence_injury_prevention/publications/road_traffic/world_report/en/index.html.

© ASCE 2014

A Framework to Identify the Sustainable and Resilient Zone of Urban Infrastructure System Planning and Design

Arka Pandit[1], Reginald DesRoches[2], Glenn J Rix[3], and John C Crittenden[4]

[1]Brook Byers Institute for Sustainable Systems, School of Civil and Environmental Engineering, Georgia Institute of Technology, 828 W Peachtree Street NW, Suite 320, Atlanta, GA 30332; Phone: (404) 894-7895; Fax: (404) 894-7896; email: Arka.Pandit@gatech.edu
[2]School of Civil and Environmental Engineering, Georgia Institute of Technology, Mason 1109, 790 Atlantic Drive, Atlanta, GA 30332; Phone: (404) 385-0402; Fax: (404) 894-2278; email: reginald.desroches@ce.gatech.edu
[3]Geosyntec Consultants, 1255 Roberts Blvd. NW, Suite 200, Kennesaw, GA, 30144; Phone: (678) 202-9500; email: GRix@Geosyntec.com
[4]Brook Byers Institute for Sustainable Systems, School of Civil and Environmental Engineering, Georgia Institute of Technology, 828 W Peachtree Street NW, Suite 320, Atlanta, GA 30332; Phone: (404) 894-7895; Fax: (404) 894-7896; email: john.crittenden@ce.gatech.edu

ABSTRACT

To meet the global challenge of infrastructure provision for 6 billion urban residents by 2050, it is imperative to incorporate sustainability and resilience as key attributes for infrastructure development/rehabilitation. However, there is no robust approach available to decision-makers to explore whether there are tradeoffs between sustainability and resilience or they are complementary. This paper presents an approach to identify the sustainable and resilient zone of urban infrastructure development. We demonstrate the efficacy of the approach through a case-study on seismic retrofit of a potable water distribution system in California. The approach along with the case study provides us with a few key insights. First, while there is an apparent tradeoff between sustainability and resilience, as increasing resilience increases capital investment; they are complementary when conceived from a life-cycle perspective. Second, there indeed exists a Sustainable and Resilient zone of planning and design, where both sustainability and resilience can be optimized together.

INTRODUCTION

Increasing urbanization is a dominant global trend of the past few decades. Provision of infrastructure to service this growing urban population for water, energy, and accessibility, is one of the major challenges faced by urban planners, engineers and other decision makers. In a world faced with a myriad of challenges ranging from a changing climate pattern to dwindling resources to an increasing number of extreme natural events to fiscal constraints, incorporation of sustainability and resilience in every aspect of urban infrastructure decision making has become a requisite condition. Going forward we need to ensure that the urban infrastructure system (UIS) that are being rehabilitated or built are

© ASCE 2014

sustainable and resilient to maximize the efficiency of resource investment while minimizing the environmental impact over the lifecycle of the project. The need for sustainable and resilient infrastructure is also emphasized by ASCE in their recent report about the state of America's infrastructure systems, which states: *"Infrastructure systems must be designed to protect the natural environment and to withstand both natural and man-made hazards, using sustainable practices, to ensure that future generations can use and enjoy what we build today, as we have benefited from past generations."*(ASCE, 2013)

While there is a growing impetus of incorporating sustainability in decision making, frequently it comes at the cost of resilience. This is attributable to the fact that the decision-makers often lack a life-cycle perspective and a proven, consistent and robust approach to understand the tradeoff between increased resilience and its impact on sustainability. In this paper, we propose an approach to quantify the losses that result from urban infrastructure system (UIS) failure and the increased investments to make UIS more resilient. The sustainable and resilient zone of UIS planning and design is defined as the zone where *'increased material and energy investment that increases the system resilience, increases the system sustainability over the life-cycle of the UIS'*(Pandit, Desroches, Rix, & Crittenden, 2013).

The Need for Sustainability and Resilience

With an increasing urban population, a changing pattern of climate, and dwindling resources; incorporation of sustainability in every aspect of development has grown from a preferred alternative to an imperative. Consequently definitions of *sustainable development* have abounded in the recent years. For the purpose of this paper we will use this general guiding principle: *we need to manage the anthroposphere (the place where humans live) to exist within the means of nature.* Adoption of this principle in UIS development requires a development strategy which minimizes the impact of material and energy investment over the lifetime of the project while increasing the creation of comfort and wealth.

Resilience is an important attribute of sustainability, as it enhances the flexibility and adaptability of the system and increases the long term benefits of material and energy investments. A recently adopted definition of infrastructure resilience is *"the ability of this system to (i) gracefully degrade its function by altering its structure in an agile way when it is subject to a set of perturbations of this class and (ii) quickly recover it once the perturbations ceased."*(Mili, 2011) This study adopts the concept of resilience as provided above. Without getting into the deliberation about the causal phenomenon, simply from an observational standpoint it can be seen that the number of extreme weather events are on the rise over the past few decades. These events are not only disruptive for human life but are also responsible for significant economic loss. National Oceanic and Atmospheric Administration (NOAA) estimates the economic losses caused by these events in 2012 will surpass that of 2011, which was pegged at $60.6

© ASCE 2014

billion (adjusted to 2012 dollars)(Smith & Katz, 2013). The frequent occurrence of these disruptive events and the massive economic losses associated with these events warrant future infrastructure to be resilient.

Is there a Complementarity or Tradeoff between Sustainability and Resilience?

There is an apparent tradeoff between sustainability and resilience. Unidirectional pursuit of sustainability optimization in the narrower sense often results in removal of components that add redundancy to the system, a crucial attribute for resilience. In the instance when the system is subjected to natural or anthropogenic stressors they will have a higher probability of failure owing to their low resilience and would need to be rehabilitated or replaced. This in turn reduces the sustainability of the system over its life cycle, as this would require a far greater need in material and energy investment than that would have been required to incorporate some degree of resilience in the first place. However, this does not answer a very important question, how much more resilient should the UIS be. This paper shows how planners can answer this question.

Sustainable and resilient zone of UIS planning and design

To illustrate this approach of UIS planning and design, we determined the seismic performance of a potable water distribution system of a hypothetical city with a population of 1 million. The city is located somewhere between 35°N-40°N and 120°W-125°W, which approximates the location of San Francisco-Santa Barbara region in the state of California. The location choice was partially influenced by the recent efforts undertaken in Alameda County, CA to seismically retrofit their entire potable water system through a public-private partnership by modestly raising the water bill of their customers(Maharaj, 2012).

We developed six hypothetical seismic retrofit scenarios that gradually reduce the expected *downtime* of the utility in case of an earthquake (EQ), where 'downtime' is conceptualized as the number of days the system remains non-functional, partly or fully, in the event of an earthquake. Figure 1 show the down time for a particular EQ intensity and retrofit cost, which includes both capital and operational costs. The

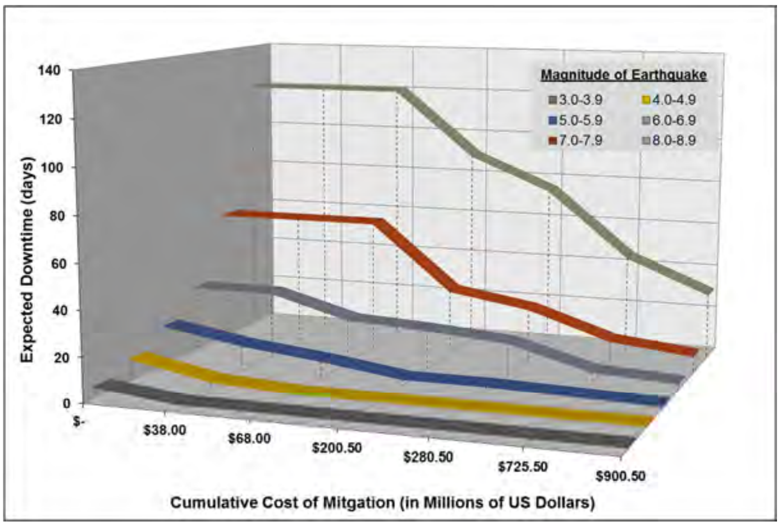


Figure 1: Cost of seismic retrofit of the potable water system for a million residents of a hypothetical located within the coordinate of 35°N-40°N and 120°W-125°W.

expected downtimes were calculated in this study based on the empirical relations between the number of pipe repair(s) required per unit length of pipeline and the peak ground velocity (PGV), which have been observed at this location(O'Rourke & Jeon, 1999; O'Rourke, Toprak, & Sano, 1998; Toprak, Koc, Cetin, & Nacaroglu, 2008). Peak Ground Velocity expresses the peak of the first integration of the acceleration record, where *acceleration* indicates the intensity, i.e. how hard the surface shakes in a given geographic area for a given earthquake. While typically EQ magnitude is used in general or non-technical communication to describe the EQ intensity, it does not convey some very essential information like the EQ point-of-origin, the subsurface condition, etc., all of which are critical in estimating its damage potential at any given location. Research has shown that PGV provides the best relationship with damage. Hence, it was used for this case-study(Yih-Min Wu, Nai-Chi Hsiao, & Ta-Liang Teng, 2004). The relation between PGV and the EQ magnitude is dependent on the particular subsurface composition of the area and the distance between the point-of-origin of the earthquake and the location. The empirical correlation that used in this study was obtained from a study conducted by Wald, et al., for the region(Wald, Quitoriano, Heaton, & Kanamori, 1999).

The Economic Cost-Benefit Analysis

The feasibility of designing and planning a UIS to increase its resilience is governed by a benefit-cost analysis (BCA). And an UIS project is feasible only when the benefit-to-cost ratio is greater than 1. A cost-benefit analysis was performed for the different mitigation scenarios using the Federal Emergency Management Agency (FEMA) BCA V4.8 toolkit(FEMA, 2013), assuming a useful project life of 50 years, a discount rate of 5% and a utility loss rate of $103.00/capita-day for every day of downtime. The benefits were assessed by calculating the damages that were avoided. The reduction of probable downtime is estimated by considering the probability of occurrence of all EQs of different magnitudes within the useful lifetime of the project. The total down time is the sum of all the downtimes that are associated with those occurrences. As shown in Figure 2, if we increase our investment in mitigation, then the avoided damage increases at first then plateaus. In other words, to

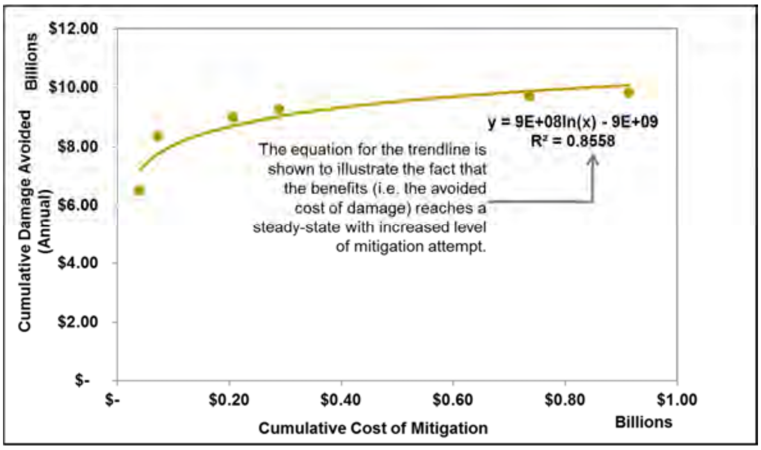


Figure 2: Benefits obtained from seismic retrofit of the potable water system, quantified in terms of economic value of avoided damage on an annual basis.

retrofit the system for low-probability high-damage potent EQs, the benefits or avoided damage do not increase that much after an investment of ~ $300 million. While all of the retrofit scenarios yielded a benefit-to-cost ratio greater than 1, it can clearly be observed that beyond a certain point, seismic retrofits to mitigate EQs with a larger damage potential, yields a dramatic reduction in BC ratio.

The Sustainability Cost-Benefit Analysis

While the method of economic CBA is an established tool, there is no tool currently available which would allow the decision-makers to assess the cost-benefit of a project from the perspective of sustainability. The Sustainable and resilient methodology introduced in this paper would provide a clear understanding about where the trade-off lies and be able to recommend the optimum options which are both sustainable and economically feasible. A life-cycle impact assessment was performed on the economic value of both the mitigation cost and the corresponding benefits obtained in the form of avoided damage. The environmental impacts of the different economic values were estimated utilizing the Economic Input-Output Life Cycle Assessment (EIO-LCA) tool(Carnegie Mellon University Green Design Institute, 2008). EIO-LCA estimates the energy and materials required for and the emissions resulting from any particular activity throughout the economy including the entire supply chain associated with the activity. The emission outputs were obtained for the different cost and benefit scenarios using EIO-LCA and TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) output(Bare, Gloria, & Norris, 2006). TRACI is a set of environmental impact categories emerging from

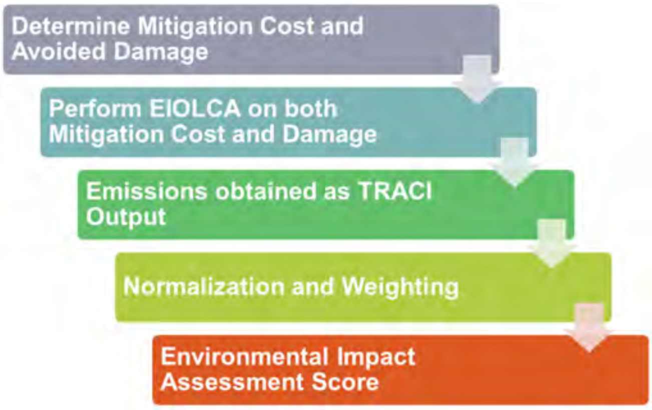


Figure 4: The process of converting the cost and benefits of seismic retrofit from dollars to environmental impacts.

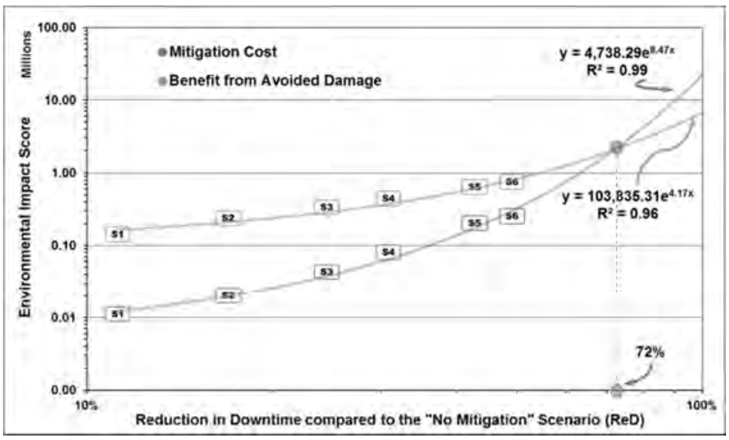


Figure 3: Cost-Benefit Analysis (CBA) of Environmental Impact Assessment (EIA). The EIA curves for both cost and benefit exhibit strong correlation with the level of ReD attempted in a retrofit scenario.

the effects of different process-related emissions to land, water and air, as developed by EPA.

The impacts for each category were then normalized by dividing the absolute values by the average emissions that are caused by an average US person. These are classified into two broader categories: (1) *'Impact to Human Health'* and (2) *'Impact to Ecosystem'*. These two categories were then preferentially weighed according to the Hierarchist perspective, which weighs the Human Health and Ecosystem equally, assigning 50% weight to each of these catergories(PRé Consultants, 2000). The environmental impact BCA was performed based on the ReD (Reduction in Downtime), defined *as the percentage of reduction in downtime achieved by a particular retrofit scenario over the lifetime of the project compared to the 'No Mitigation' scenario*. ReD is calculated by considering the EQ magnitude, the probability of its occurrence and the downtime associated with each EQ event. The Environmental Impact Score (EIS) for the costs of and benefits obtained from each retrofit scenario are shown in Figure 4. It might be noted that the EIS reports the impact in terms of the average impact of an US person over a year.

While the EIA curves for retrofit cost and associated benefits provide us with the a particular ReD value beyond which the impacts from the investment in retrofit outweighs the benefits from damage avoidance, it does not provide an optimum zone of planning and design where both sustainability (measured as net environmental benefit) and resilience (measured as ReD attainment) can be optimized together. A plot of net environmental benefit in terms of EIS against attainment of ReD generates the Sustainable and resilient curve (Figure 5), which provides a clear indication about the sustainable and resilient zone of UIS planning and design.

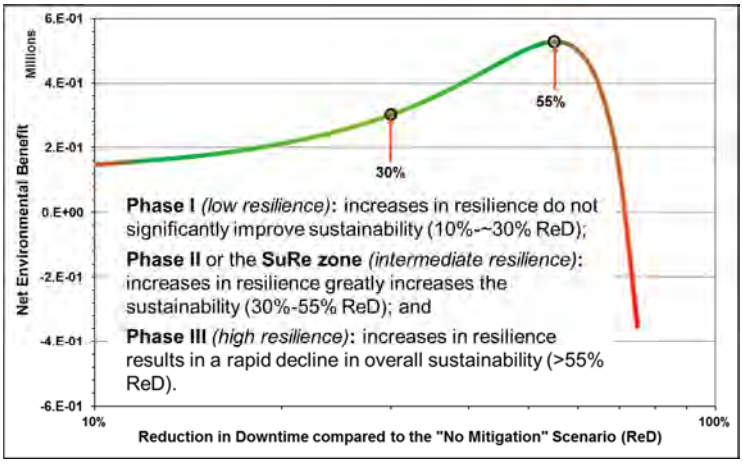


Figure 5: The Sustainable and Resilient Curve. It is characterized by three distinct phases based on the correlation between attainment of ReD in a retrofit and Net Environmental Benefits.

Adoption of the Sustainable and Resilient Curve in UIS Design and Planning

The concept outlined herein and the case study provides us with a few key insights. First, while there is an apparent trade-off between sustainability and resilience, in the sense that increasing resilience warrants increased material and energy investment. In actuality they are complementary when conceived holistically from a life cycle perspective. Second, there indeed exists a zone of

© ASCE 2014

planning and design, the Sustainable and resilient zone, where both sustainability and resilience can be optimized together. However, it must be noted that this zone is not universal either across the spectrum of infrastructure sectors or spatially. Actually, this zone needs to be identified for different infrastructure sectors and for varying topographic and demographic conditions.

Acknowledgement

This research was supported by the Brook Byers Institute for Sustainable Systems, Hightower Chair, and the Georgia Research Alliance at the Georgia Institute of Technology. The authors are thankful for a grant (#0836046) from the National Science Foundation program for Emerging Frontiers in Research and Innovation (EFRI).

References:

ASCE. (2013, March 19). 2013 Report Card for America's Infrastructure. *America's Infrastructure G.P.A*. Retrieved March 19, 2013, from http://www.infrastructurereportcard.org/a/#p/grade-sheet/gpa

Bare, J., Gloria, T., & Norris, G. (2006). Development of the method and U.S. normalization database for Life Cycle Impact Assessment and sustainability metrics. *Environmental Science & Technology*, *40*(16), 5108–5115.

Carnegie Mellon University Green Design Institute. (2008). Economic Input-Output Life Cycle Assessment (EIO-LCA), US 2002 Industry Benchmark model. *eiolca.net*. Retrieved March 20, 2013, from http://www.eiolca.net

FEMA. (2013, February 1). Benefit-Cost Analysis. *Federal Emergency Management Agency, Benefit-Cost Analysis*. Retrieved March 20, 2013, from http://www.fema.gov/benefit-cost-analysis

Maharaj, Z. (2012, November 21). Water District Proposes Rate Increase for 2013. *Union City Patch*. Union City, CA. Retrieved from http://unioncity.patch.com/groups/politics-and-elections/p/water-district-proposes-rate-increase-for-2013

Mili, L. (2011). Taxonomy of the Characteristics of Power System Operating States. In *Proceedings of the 2nd NSF-RESIN workshop*. Tucson, AZ.

O'Rourke, T. D., & Jeon, S. . (1999). Factors affecting the earthquake damage of water distribution systems, Optimizing Post-Earthquake Lifeline System Reliability. In W. M. Elliott & P. McDonough (Eds.), *Proceedings of the 5th U.S. Conference on Lifeline Earthquake Engineering* (pp. 379–388). Seattle, WA: American Society of Civil Engineers.

O'Rourke, T. D., Toprak, S., & Sano, Y. (1998). Factors affecting water supply damage caused by the Northridge earthquake. In *Proceedings of the 6 th US National Conference on Earthquake Engineering* (pp. 1–12). Seattle, WA.

© ASCE 2014

Pandit, A., Desroches, R., Rix, G. J., & Crittenden, J. C. (2013). The SuRe (Sustainable and Resilient) Zone of Urban Infrastructure System (UIS) Planning & Design. *Solutions*.

PRé Consultants. (2000). *Eco-indicator 99 Manual for Designers* (Manual). Amsterdam. Retrieved from http://www.pre-sustainability.com/download/manuals/EI99_Manual.pdf

Smith, A. B., & Katz, R. W. (2013). US billion-dollar weather and climate disasters: data sources, trends, accuracy and biases. *Natural Hazards*. doi:10.1007/s11069-013-0566-5

Toprak, S., Koc, A. C., Cetin, O. A., & Nacaroglu, E. (2008). Asessment of Buried Pipeline response to Earthquake Loading by using GIS. In *Proceedings of the 14 th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China*. Beijing, China. Retrieved from ftp://128.46.154.21/spujol/Andres/files/06-0077.PDF

Wald, D. J., Quitoriano, V., Heaton, T. H., & Kanamori, H. (1999). Relationships between Peak Ground Acceleration, Peak Ground Velocity, and Modified Mercalli Intensity in California. *Earthquake Spectra*, *15*(3), 557–564. doi:10.1193/1.1586058

Yih-Min Wu, Nai-Chi Hsiao, & Ta-Liang Teng. (2004). Relationships between Strong Ground Motion Peak Values and Seismic Loss during the 1999 Chi-Chi, Taiwan Earthquake. *Natural Hazards*, *32*(3), 357–373. doi:10.1023/B:NHAZ.0000035550.36929.d0

© ASCE 2014

The Broader Environmental Impacts of Combined Heat and Power (CHP) Systems using an Infrastructure Ecology Approach

J.C. James[1, 2], A. Pandit[1, 2] and J.C. Crittenden[1, 2]

[1]Brook Byers Institute of Sustainable Systems, Georgia institute of Technology, 828 W. Peachtree Atlanta, Ga 30332
[2]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, Ga 30332

Abstract

Cities are growing at a rapid pace and as such they are at the main stakeholders through which global sustainability can be reached. To this end cities have to improve the sustainability and resilience of the infrastructure systems on which they rely. The infrastructure systems are akin to ecological systems in that they are interconnected and transfer resources between each other as well as with the environment. The concept of infrastructure ecology can be used to examine how infrastructure systems within a city interact.In this study we analyzed the impact a combined heat and power system, which consists of an air-cooled microturbine and an air-cooled absorption chiller, can have on the energy and water for energy requirements of a medium sized office building. The microturbine and absorption chiller are used to supply the thermal load, which consists of heating, hot water and cooling loads of the building with the boiler and the absorption chiller meeting any loads not met. We looked at the partial loads of five microturbine systems, that ranged in capacity from 30kW to 150kW, and varied their outputs from 10%-100%. We found that running the largest CHP system at 100% will not meet the entire electrical load of the building but, will produce 10 times the thermal output required by the small office building. The 'water for energy' savings can be reduced to almost zero by the 150kW turbine running at 100% .The 150kW turbine at 100% mitigates the 'water for energy', of a building with similar characteristics, if allowed to sell excess electricity produced to the grid. Further analysis is being done to look at the emissions and economic impacts of these CHP systems.

Introduction

Increasing urbanization places cities at the forefront of achieving global sustainability. For cities to become more sustainable, however, the infrastructure on which they rely must also become more efficient and resilient. Urban infrastructure systems [2] are analogous to ecological systems because they are interconnected, complex and adaptive components that exchange material, information and energy among themselves and to and from the environment, and exhibit characteristic scaling properties. Analyzing them together as a whole, as one would do for an ecological system, provides a better understanding about their dynamics and interactions, and enables system-level optimization.

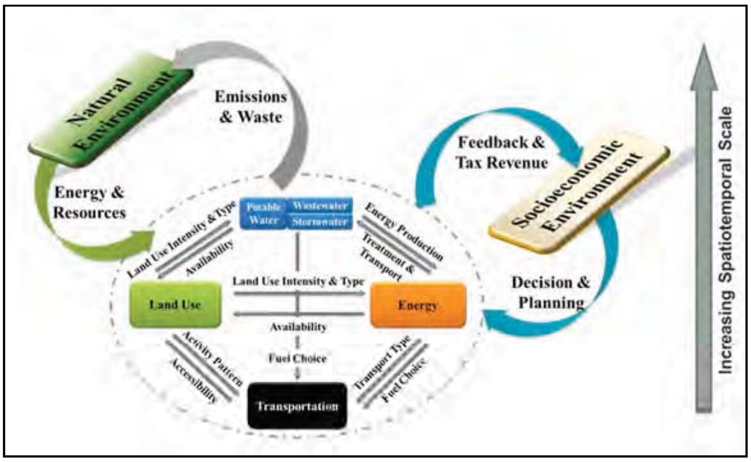


Figure 1: Interconnectedness within the UIS and the interrelations of UIS with Natural Environmental Systems and Socio-Economic systems.

The concept of infrastructure ecology can be applied specifically to UIS when the components are

© ASCE 2014

considered as an interlinked system constituting a *'Material-Water-Energy-Land Use-Transportation-Socioeconomic Nexus'*. UIS can be envisioned as complex dynamic adaptive systems comprised of six major components: economic flows resulting from infrastructure investment, drinking water, storm water and wastewater infrastructure, energy infrastructure, transportation infrastructure and land-use. These components are interconnected across spatiotemporal boundaries and when analyzed holistically, function analogous to complex ecological systems (Figure 1). In addition, the UIS are also interconnected with the natural environment and the socio-economic systems. Designing the UIS with an infrastructure ecology approach radically alters and reorganizes the flows of energy and resources within the urban region, which allows one to consider the synergistic effects arising from *infrastructural symbiosis*. While individual technologies do exist to account for these effects their applications remain sparse and fragmented[3]. In this paper we will look at the impact of changing one component of the UIS by analyzing the potential impact a Combined Heat and Power (CHP) system, located in Atlanta Georgia, can have using an infrastructure ecology approach.

Methodology

The potential energy and 'water for energy' impacts for a medium office building were determined using combined heat and power (CHP) systems. 'Water for energy' is the water required to generate a unit of energy. The CHP system consists of an air-cooled microturbine, which provides hot air and hot water, and an absorption chiller which converts the hot air produced by the turbine to cold air (Figure 2). This allows for a design in which a CHP system can meet the thermal demand, which is the hot air, hot water and cold air, of a building. The system is designed so that during the winter heat is supplied directly by the microturbine and in the summer months the heat is converted to cooling using an absorption chiller. The thermal loads of the building in the scenarios which consider the use of microturbines consist of the heating, hot water and cooling loads of the building. We assumed in the CHP scenario that any thermal demand that cannot be solely met by the microturbine is then met by the furnace. In other words the building did not have an air-conditioning unit to meet the excess thermal load that may be required during the summer. We did this because the overall efficiency of using a furnace and absorption chiller is actually greater than using an air-conditioning unit that runs off electricity from the grid. The baseline scenario assumed that the thermal loads only consist of hot water and heating. The cooling load of the building is provided by the existing electrical grid.

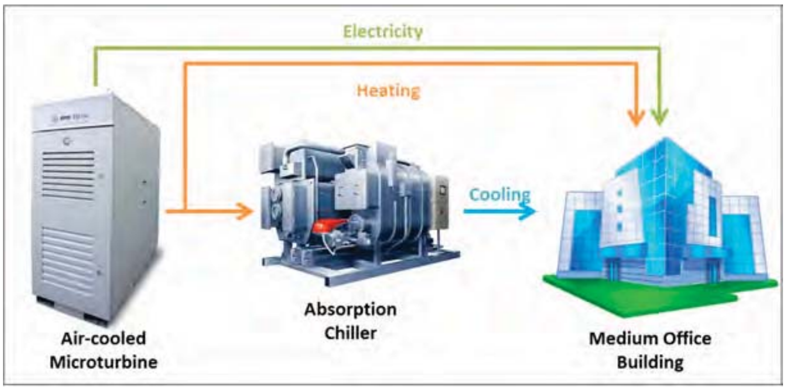


Figure 2: Setup of combined heat and power (CHP) system.

© ASCE 2014

The hourly energy requirements of a medium-sized office building were obtained from the DOE website openei.com. The characteristics of the medium-sized office building are based on the U.S. Department of Energy commercial reference buildings model[1]. These reference buildings are representative of more than 50% of the U.S. commercial building stock. Table1 lists the characteristics of a medium sized office building developed by the U.S. Department of Energy. The dataset used in this analysis is representative of a medium sized office building located in the Atlanta region.

Table1: Characteristics of Medium Sized Office Building

Floor area	53,628 ft^2
Number of floors	3
Building type	Steel frame
Cooling system	Precision Air Conditioning Unit
Heating system	Furnace

In this paper we looked at 5 microturbines of varying capacities: 30kW, 60kW, 90kW, 120kW and 150kW. 30kW microturbines are commercially available and all larger systems are made up of multiple 30kW systems. The electrical and thermal output of each microturbine operating at various partial loads was analyzed. We examined the outputs of each microturbine if they were run at a partial load of 10% constantly throughout the year up to running full out at 100% for the entire year. The thermal and electrical efficiency of the microturbines was determined using the fuel efficiency curve, for a natural gas microturbine with a heat recovery ratio of 75%, generated by HOMER. The curves generated by HOMER result in the electrical and thermal efficiency of the microturbine operating at various partial loads.

The electrical and thermal output of the microtubines at various partial loads along with the building demand data was used to determine the additional energy required from the electrical gird and or a boiler. It was assumed that the microturbines will be run at a given partial load constantly throughout the year. We assume two cases when considering the electricity provided by the CHP system. The first is that the electric grid allows for net metering; if the electricity provided by the CHP system at any given hour is greater than what is required by the building then excess electricity can be sold to the grid. The second is that excess electricity cannot be sold to the grid.

Using the additional energy required from the grid in net metering case and no net metering case we found the water for energy that would be required by the building. Based on Georgia's energy generation mix 1.65 gallons of water is consumed for every kWh of energy consumed[4]. It is assumed that no water is lost from the CHP system as the microturbine and the absorption chiller are air-cooled. The emissions from the system were calculated by summing the emissions from a microturbine operating at a given partial load, the emissions from the grid and the emissions from the boiler when the turbines cannot meet the total building load.

© ASCE 2014

Results and Discussion

The max thermal efficiency of the system based on the results generated in HOMER is 58% and the max electrical efficiency is 23%. The max thermal and electrical efficiencies remain the same for all five turbine capacities. The hourly electrical and thermal demand by the building and the outputs of the microturbines at a partial load of 10% and 100% are shown in Figure 3 and Figure 4. As shown in Figure 3, running the largest turbine at 100% will still not meet the electrical demand required by the building and that corresponds to the turbine providing 10 times the yearly thermal load required by the building. A 30 kW turbine operating at 10% throughout the year will provide 75% more thermal energy and ~4% of the electrical that is required by the building in a year. This may seem counter intuitive as Figure 4 seems to suggest that the excess thermal energy produced would not be that great especially since a furnace is still required to meet what is 38% of the buildings' yearly thermal load. This occurs because of the hourly variation in the thermal demand that cannot be seen in the figure. Therefore, the amount of heat that is wasted is greater than what is shown in Figure 4.

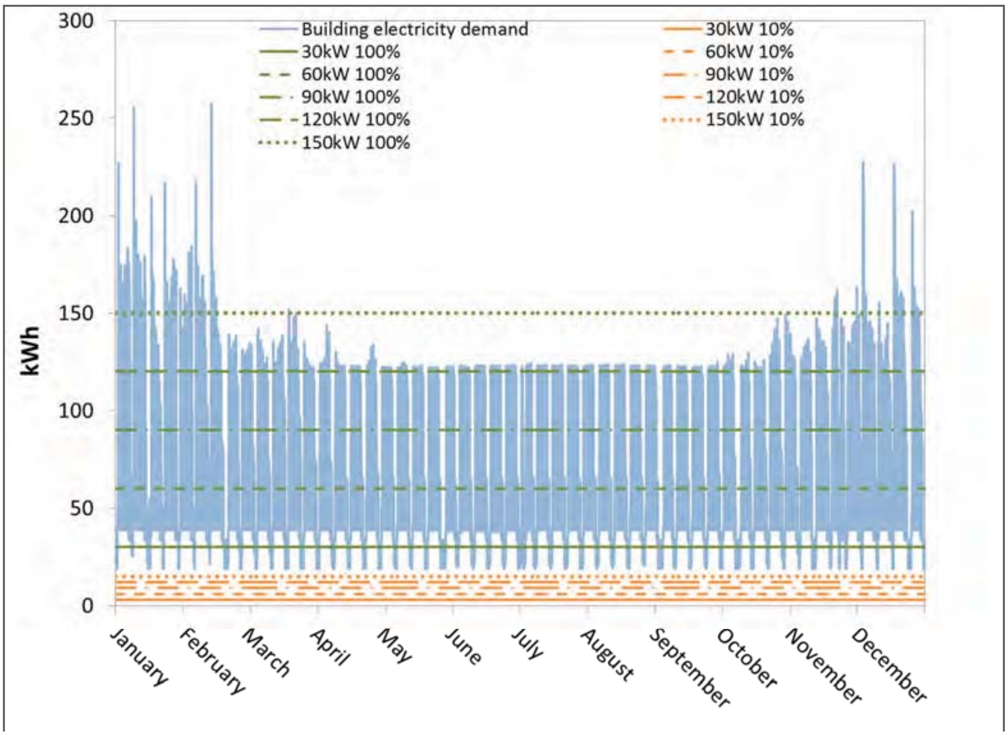


Figure 3: Hourly electrical demand of medium office building and the electrical output of a 30kW, 60kW , 90kW, 120 kW and 150kW turbine sized CHP system at 10% and 100% partial loads.

© ASCE 2014

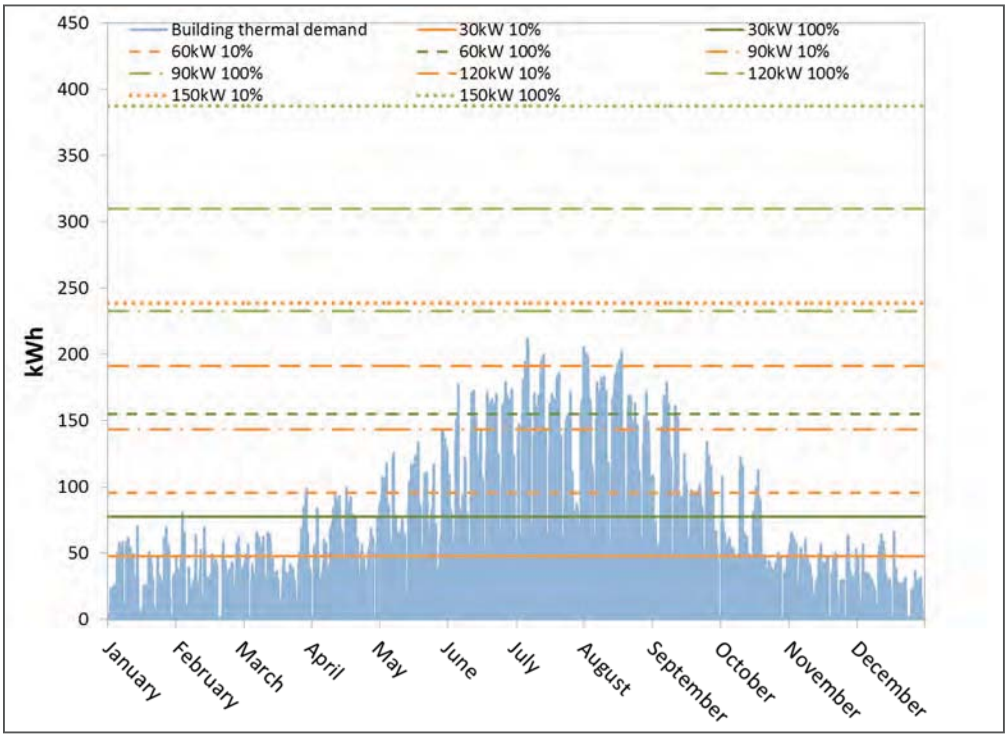


Figure 4: **Thermal demand of medium office building and the electrical output of a 30kW, 60kW, 90kW, 120 kW, and 150kW turbine sized CHP system at 10% and 100% partial loads.**

The water for energy required by the building is always less than the water for energy requirements if no CHP system is used. In the case where there is no net metering the water for energy required by the building approaches zero. When there is no net metering the water for energy never reaches zero because as shown in Figure 3 the largest turbine considered in this study can never fully meet the building electrical requirement for the entire year. In the case with net metering where electricity is allowed to be sold to a utility, at microturbine capacities of 90kW, 120kW and 150kW, the water for energy required in a year is negative. This means that the system is able to sell back enough energy to reduce the buildings water for energy footprint to zero and offset the water for energy that would be required by other buildings. In the case of the 150kW microturbine running at 100%, the water for energy of a second building of the same size and energy demand can be mitigated.

© ASCE 2014

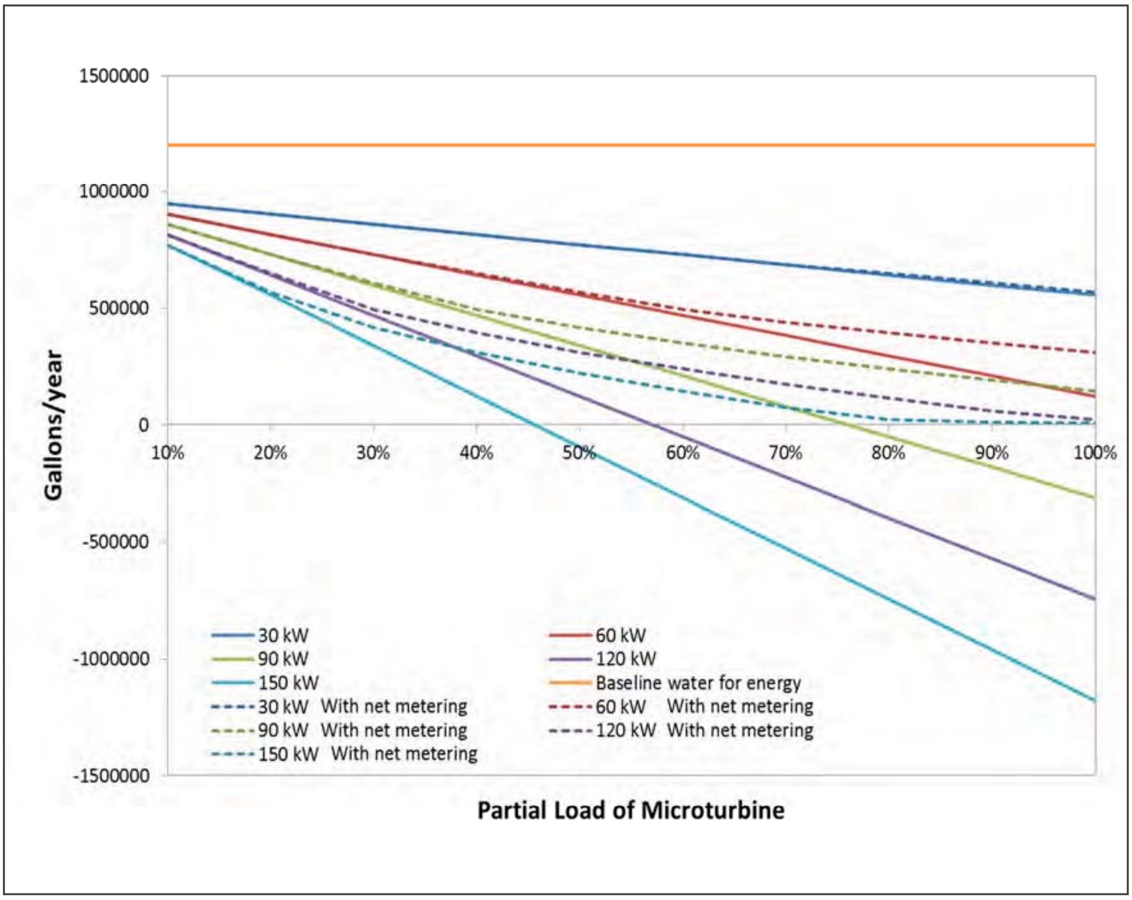


Figure 5: Water for energy required for a medium office building for various microturbine sizes at different partial loads and with net metering.

Future work

To further link other UIS components we will examine the cost implications of running these CHP systems at various partial loads. Using the methodology developed in this paper we will conduct a similar analysis on 2 other office building types, small and large, and 2 residential buildings. Using these building types we can analyze the water for energy, energy and emissions impacts of implementing CHP systems on a city/ metropolitan scale. We will also look at the impact thermal storage can have on each building and a city.

References:

[1]Deru, M.; Field, K.; Studer, D.; Benne, K.; Griffith, B.; Torcellini, P.; Liu, B.; Halverson, M.; Winiarski, D.; Rosenberg, M., US Department of Energy commercial reference building models of the national building stock. 2011.

[2]Lautier, A.; Rosenbaum, R. K.; Margni, M.; Bare, J.; Roy, P.-O.; Deschênes, L., Development of normalization factors for Canada and the United States and comparison with European factors. *Science of The Total Environment* 2010, *409* (1), 33-42.

[3]Pandit, A. J., H.; Crittenden J.C.; French S.P.; Xu M.; Li, K., Susatainable infrastructure and alternatives for urban growth. *Sustainability: Multi-disciplinary perspectives* 2012; pp 141-172.

[4]Torcellini, P. A.; Long, N.; Judkoff, R. D., Consumptive Water Use for US Power Production. *ASHRAE Transactions* 2004, *110* (1).

© ASCE 2014

Sustainable Transportation Systems for Dhaka Metropolitan City: Issues and Opportunities

Md. Shoaib Chowdhury, PhD, PE, M.ASCE [1]

[1]Adjunct Associate Professor, Department of Civil Engineering, The City College of New York, 160 Convent Avenue, New York, NY 10031; PH (201)-963-4136; email: mchowdhury@ccny.cuny.edu

ABSTRACT

Dhaka, the capital of Bangladesh, with over 15 million people within its area of 360 square km, has emerged as one of the most congested, unsafe and polluted cities in the world today. The capital city relies on its road based transportation system. However, the roads of Dhaka are not well planned, designed and operated to meet the dwellers mobility and accessibility needs. A major portion of Dhaka's some 1868 km of roadways has no sidewalks and where the sidewalks do exist, they are very narrow, poorly maintained, and disjointed/broken. Buses are the only form of mass transit mode in Dhaka and bus operators are mostly privately owned fragmented and unorganized companies. They provide substantially inadequate and very poor quality of bus service.

For its very existence as a mega-city, Dhaka needs to develop a healthy transportation system to support its existing population as well as to maintain a sustained growth. Given the "status-quo", this paper addresses six critical issues (e.g., transportation infrastructure and pedestrian, public transportation, growth management and control, education and research, governance and institutions, and funding and financing), and needs in light of developing sustainable transportation systems for Dhaka metropolitan city.

INTRODUCTION

Dhaka is the capital city of Bangladesh with an area of 360 Sq km under the district of Dhaka and it has emerged as one of the most congested, unsafe and polluted cities in the world today mainly due to its (1) long negligence in the development of effective transport, land use and environmental policies and planning (2) inadequate investments on transport infrastructures over a sustained period, (3)) lack of the development of sound public transportation systems and services, and (5) poor traffic and growth management initiatives including internal migration control.

The estimated population of Dhaka metropolitan city is over 15 million and the population has been growing at a rate of 3 to 4 percent *(Muzzini and Aparicio, 2013)***.** With a centrally administrated government of Bangladesh, Dhaka has emerged as the administrative, economic, commercial, industrial, socio-political and cultural center of the country while contributing approximately 36% of the nation's Gross Domestic Product (GDP) *(Muzzini and Aparicio, 2013)***.** It is also one of the densely populated and fastest growing mega cities in the world today *(MoEF, 2012; World Bank, 2007)***.** The internal migrants, an estimated at 300,000 to 400,000 per year, from rural and smaller urban areas are the major contributors in the growth of city population *(World Bank, 2007; Chowdhury, 2008)*. Rapid expansion of city is also fueled by the housing construction boom initiated by the real estate developers. In the last two decades or so, a large number of residential and commercial high rise buildings have been built and the prospect for further development is very high *(REHAB, 2012)***.**

© ASCE 2014

Dhaka relies on its road based transportation system, however, the city's road network is not well planned, designed and operated to meet the dwellers mobility and accessibility needs. The road infrastructure is substantially inadequate and the roads are generally very narrow. Contrary to developed nations, where generally 20% to 30% of the land is dedicated for transportation purposes, Dhaka merely has 7 percent of the land for the same purpose. Though, there exists an opportunity to develop circular waterways around the city, however, such an option has never been adequately explored. The modal share in Dhaka include 5.1 percent Car, 38.3 percent Rickshaw, 19.8 percent Walk, 28.3 percent Public Bus, and 8.4 percent other modes (e.g., taxi, 3-wheelers, motor-cycle etc) *(DTCA, 2014)*.

Over 60% of the city dwellers are poor; walk is the only form of transportation mode for many poor's *(DTCA, 2014)*. However, a major portion of Dhaka's some 1868 km of roadways has no sidewalks and where the sidewalks do exist, they are very narrow (effective width is generally less than 4 feet), poorly maintained, and disjointed/broken (See Fig. 1). The sidewalks are often illegally occupied by the roadside businesses and land owners forcing pedestrians to share the same roadway space with motorized vehicles jeopardizing their lives (Fig. 1 C, E & I F). The road intersections are poorly controlled and managed. For instance, only 70 intersections are signalized (pre-timed) out of some 650 intersections that are existed on Dhaka's 1868 km of roadways. Many intersections are not at all controlled and some are manually controlled by the traffic police. Despite auto ownership is very minimal (5 percent or so); Dhaka roadways are very congested especially during the peak periods.

Dhaka has yet to develop a mass transportation system. Currently, the Bangladesh Road Transport Corporation (BRTC), a poorly funded public agency, provides bus service on few selected routes covering only a small area of the large metropolis. Privately owned and operated bus companies are very fragmented and unorganized. They provide substantially inadequate and very poor quality of bus service (See Fig. 1A). Nonetheless, inadequate road infrastructures coupled with insufficient and poor public transportation services have been degrading the mobility of dwellers as well as hampering livelihoods, physical and environmental heaths, economic growth and productivity.

For its very existence as a mega-city, Dhaka needs to develop a healthy transportation system to support its existing population as well as to maintain a sustained growth. Given the "statu-quo", this paper addresses existing issues and needs from a very high level prospective in six key areas including transportation infrastructure and pedestrian, public transportation, growth management and control, education and research, governance and institutions, and funding and financing that are critical in support of developing sustainable transportation systems for Dhaka metropolitan city.

ISSUE # 1: TRANSPORT INFRASTRUCTURE AND PEDESTRIAN

The transportation network of Dhaka city consists of some 1868 km of roads and 163 km of sidewalks (footpaths) *(Sultana, 2013)*. The road network is very irregular with many broken links causing serious connectivity problems and roads are generally operated uncontrolled permitting direct access of vehicles from abetting lands (e.g., gas stations, shopping malls, driveways etc) and cross streets (e.g., un-controlled intersections) undermining the mobility function of roadways. As the city rapidly expands towards north, the north-south traffic flow becomes the dominating traffic flow directions. Though, there exist some continuous north-south corridors, however, there is no well connected east-west corridor and the road connectivity along east-west direction is generally poor. A recently completed east-west connecting roadway segment (e.g. Hatir-zheel project) takes the heavy burden in facilitating east-west traffic flow.

© ASCE 2014

A. A passenger trying to board a small bus in the middle of the street

B. A major signalized intersection with haphazard traffic and pedestrian movements

C. motor cycle on sidewalk

D. Uncontrolled T-intersection

E. Sidewalk illegally occupied

F. Pedestrians randomly crossing street; Rickshaw occupying a major portion of roadway while idling;

Figure 1. Typical issues with road transportation in Dhaka city.

Dhaka city has yet to develop policies on controlling roadway intersections. As such, currently the city has no legal obligation requiring the control of intersections (See Fig. 1D). The Bangladesh Road Transport Authority (BRTA), a semi-autonomous regulatory body, has developed some standard traffic control devices (e.g., signs, street names, markings etc) though they are not exhaustive. It seems a standard manual on uniform traffic control devices (e.g., signs, signals, street names, markings etc) particularly addressing the legal requirements for intersection control is urgently needed. As observed by the author, timing plans (pre-timed signal) of many of the 70 signalized intersections within the city are poorly designed while maintaining long cycle lengths (in some cases exceeding five minutes). Furthermore, due to lack of proper maintenance, signals frequently fail to function (See Fig. 1 B) properly creating

© ASCE 2014

intersection operations unsafe for both pedestrians and vehicular traffic. The city agency lacks signal design tools and technical skills to ensure the development of optimal signal timing plans. The traffic police are responsible for controlling and managing the city intersections. Due to lack of effective coordination between the city agency and traffic police, actively operated signals are often manually controlled by traffic police overruling the legal timing plans. Due to inadequate training and limited resources, police finds it difficult to control and manage the intersections efficiently.

Congestion on Dhaka roadways is very prevalent with a worst case average speed of 7.0 km per hour as observed by the author. Many roadways still allow motorized and non-motorized vehicular traffic to share the same roadway space. On-street parking/standing is poorly managed and enforced. Due to significant shortage of off-street parking (for car only off-street parking accommodation is very limited), vehicles (e.g., car, trucks, rickshaws, auto-rickshaws, etc) illegally park on-street causing congestion (See Fig. 1 F).

Pedestrians are very vulnerable as they cross streets due to the fact that pedestrians are rarely accommodated at intersections formally with marking crosswalks. Specially, un-signalized intersections are very dangerous for pedestrians to cross as drivers rarely yield for them. Intersections are not designed to accommodate large volume of pedestrians as there is no provision for holding pedestrians (e.g., refuge islands and wider sidewalks) at intersection corners as they wait before crossing the streets. Although there are sporadic pedestrian overpasses, pedestrians seldom use them. Based on a survey conducted by the author, it reveals that pedestrians are generally uncomfortable to climb on very high overpasses, overpasses are also insecure at times, capacity is substantially inadequate to accommodate high volume of pedestrians and some overpasses are even unusable as they are occupied by illegal businesses. The pedestrians indiscriminately cross streets/roads at any points (where feasible) along roadways (e.g., at midblock) risking their lives (See Fig. 1F) as intersections and overpasses cannot adequately accommodate large volume of pedestrians. The pedestrian fatality data showed that a total of 300 pedestrians have been killed in year 2008 within the Dhaka Metropolitan city making it 78% of the total road fatalities in the metropolis *(BRTA, 2008)*. For instance, the pedestrian fatality in the USA is around 12 % of all road fatalities *(ITE, 2009)*. With pedestrian representing a large share of traffic fatalities and over 100 fatalities per ten thousand registered motor vehicles in Bangladesh, the traffic and pedestrian fatalities in Bangladesh could be at least fifty times higher than the Western Europe and North American nations (MoC, 2009).

There are approximately 400, 000 active rickshaws on Dhaka city roadways, though only 85,000 rickshaws are licensed by the city corporation *(Wikipedia, 2014)*. The strength of rickshaw is that it is non-polluting (non-motorized) mode. Some of those rickshaws are battery powered (low polluting). Rickshaw generally accommodates 2 passengers and travel at around 10 to 15 kilometers per hour depending on roadway condition. The major weakness is that large volumes of rickshaws occupy huge roadway space (See Fig. 1F) and at present there are no off-street rickshaw stands. There are also large numbers of auto-rickshaws (powered by Compressed Natural Gas: CNG) and taxis on city streets without having their own off-street facilities to pick up/drop-off passengers. Based on the issues discussed above, critical needs are identified and listed below:

- ✓ A comprehensive plan is needed to redefine the street systems with appropriate functional classifications (e.g. arterials, collectors and local roads) while balancing the dwellers mobility and accessibility needs. Where feasible, roadways and sidewalks must be widened

© ASCE 2014

and network connectivity must be improved with the additional new roadways or re-aligning existing roadways.

- ✓ Priority must be given to pedestrians (pedestrian mode share is 19.8%) with the development of well connected and continuous pedestrian path/network all across the city. Specifically sidewalks (with adequate width) along all roadways need to be built. Furthermore, safe street crossings need to be ensured for pedestrians by accommodating them at all designated pedestrian crossing locations. In this regard, identification of pedestrian crossing needs is very critical.
- ✓ Though rickshaw would not be allowed to coexist with high speed motorized modes on arterial roadways, however, with well plan, rickshaw can still be efficiently utilized in neighborhood streets to serve as an environment-friendly feeder mode to public transportation, to serve the neighborhood as well as to provide service to tourists. However, number of rickshaws need to be controlled to maximize their utility while planning for their accommodations at transit stations and off-street locations.
- ✓ Rickshaw, auto-rickshaw (CNG), taxi etc needs to be accommodated at roadside locations (off-street) as they wait for passengers to save limited roadway space.
- ✓ There is a need for a comprehensive parking study towards finding an optimal parking solution while utilizing all available on and off-street parking spaces.
- ✓ A regulation and an standard practice requiring the installation of appropriate traffic control devices (e.g., signal, and stop/yield control) will be needed to improve roadway operations, and safety (with special attention to pedestrian safety).

ISSUE # 2: PUBLIC TRANSPORTATION

At present, there is no well defined and organized public transportation system in Dhaka. Buses are the only form of mass transit mode. There are some 2312 large and 3146 small buses operate along 170 routes in Dhaka city *(BRTA, 2014)*. Beside Bangladesh Road Transport Corporation (BRTC), a State owned semi-autonomous body that operates buses on 11 routes *(BRTC, 2014)***,** all other bus service providers are private companies and individual owners *(Sultana, 2013)*. The profit motivated and loosely formed private providers often compete with each other delivering overlapping services on high ridership routes and very infrequent service on low ridership routes. They are also reluctant to improve transit service quality and expand service area coverage as their goal is to maximize profit rather than to meet social needs. Bus routes are not given any preferential treatment and thus buses operate in a mixed traffic maintaining a very slow speed. Moreover, bus routes are not integrated at network level though buses on some routes do overlap at some places. Due to poor (e.g., informal schedule and overcrowding) quality of bus service, a large number of trips are made on foot (walk) and those could have been the bus riders provided a better service ensured.

Despite there is a very high demand for a public transportation services (modal share is 28.3% (*DTCA, 2014)*), government's investment priority seems more towards road projects than transit projects. For instance, recent capital construction projects such as Hatir-Zheel, Mayor Mohammad Hanif Flyover, Kuril flyover, Moghbazar-Mouchak flyover, and the Banani level crossing are all road improvement projects *(MoF, 2013a)*.The recent transit initiatives include the completion of feasibility study and preliminary design of a world bank financed 22-kilometer long (16-station) Bus Rapid Transit (BRT) project. The Dhaka Transport Coordination Authority (a regional coordination authority for transportation policy, planning and project development) has been overseeing the 20.1 km long (16-station) Metro Rail Transit line study that would potentially be built with the assistance of Japan International Cooperation Agency (*DTCA,*

© ASCE 2014

2014). Upon completion of the Metro Rail Transit line, a newly conceptualized government agency named Dhaka Mass Transit Company Ltd (DMTCL) will take control of its operation, management, and maintenance related responsibilities (*MoF, 2013*). However, history shows that often foreign funded projects have been cancelled or delayed for many different reasons making some doubts that whether the project at all will be implemented or not.

Given the discussion made, this paper identifies the need for developing a comprehensive public transportation policy with a goal of providing high capacity faster transit service at an affordable cost to its poor dwellers at earliest possible time, while utilizing diversified funding and financing sources (as will be discussed in the funding and financing section). Particularly, it suggest the development of an inter-and-multi-modal transportation system by integrating well the motorized (e.g., three-wheelers/Scooters/CNG, taxi, Metro Rail, LRT, BRT, local bus etc) and non-motorized (e.g., walking, biking, and rickshaw etc) modes. Mass transport network (e.g., BRT, LRT, Metro Rail etc as feasible) should be integrated well with feeder route networks (e.g., bus, taxi, rickshaw etc. as feasible) while appropriately addressing the pedestrian circulation and access needs.

ISSUE # 3: GROWTH MANAGEMENT AND CONTROL

Dhaka was never been a well planned city. Over the years and decades, it has grown uncontrolled. Yet today, there is no serious concern for managing the growth and developments. RAJUK (a semi-autonomous body for land control and development), is the authority to manage the growth and developments within the Dhaka metropolitan city *(RAJUK, 2014)*. It approves industrial, commercial and residential development projects. However, due to its weak policy and planning laws, as well as inadequate enforcement capacity, RAJUK has been failing to fulfill its obligations *(Chowdhury, 2008)***.** A large number of infrastructures (e.g., residential, commercial and industrial buildings) in Dhaka city are illegal. As Chowdhury *(Chowdhury, 2008)* indicated**,** some 16,000 high rise buildings have been constructed in Dhaka without the approval of RAJUK indicating that a large percentage of development activities (land development) in the city are illegal.

There is a strong interaction between transportation and land use. Yet, there are no integrated policies and plans for land use and transportation in Dhaka. Land use policies and plans are developed, implement and enforced by RAJUK, while The Dhaka Transport Coordination Authority (DTCA) is responsible for the coordination of transportation policies and program *(DTCA, 2014)*. Land use and development (structured plan and zoning) plans are made by RAJUK independently without considering its impact on transportation systems and services. In recent decades, many educational institutions (e.g., private universities) were built without giving due considerations on how these developments will have impact on transportation systems and services, how the educational institutions will meet their transportation needs, what improvements will be needed from transportation systems and services prospective to accommodate additional demands and so on. Today, the city dwellers are paying the price as those developments are partially responsible for chronic roadway congestions and subsequent air pollutions. Given the lessons learned, Dhaka needs to act on the following to manage the growth and control

- ✓ Formulate integrated policies, plans and programs on transportation, land use and environment

© ASCE 2014

- ✓ Introduce the requirements of traffic impact and environmental assessment mandatory for large scale development projects for sustainable development (e.g., any new development must be burdened with appropriate transportation and environmental impact fees)
- ✓ Control internal migration by articulating appropriate policies to redistribute the economic activities all across the country specifically in rural areas and small towns (This should be the responsibility of national government)

ISSUE # 4: EDUCATION AND RESEARCH

Sustainable urban development has been challenged by the rapid growth and developments. Thus, urban transportation problem becomes much more complex than ever before as sustainable development requires multidisciplinary and coordinated efforts simply because any action taken with respect to transportation affects the environment, land use, safety/public health and so on and vise versa. In this regard, governance, institutional settings and arrangements (e.g., coordination and collaborations), and funding and financing policies should be supportive of sustainable developments. To meet those challenges, high quality and sustained (e.g., continuous) research is needed in many different areas involving multidisciplinary experts. For instance, research is needed to innovate and develop effective policies and planning, laws and regulations as well as tools and methods, models and study guidelines, standards practices and procedures and so on.

Given that each urban area is unique from a socio-economic, cultural, and development prospective, solution to a specific transportation problem could be quite different from one locality to another. Thus, solving complex urban transportation problems in a sustainable manner requires locally based strong inter-disciplinary research program. Bangladesh is far behind in this regard. For instance, besides the Accident Research Institute (ARI) at Bangladesh University of Engineering and Technology (BUET) that conducts researches on transportation safety, no other research institutions can be found that conducts researches on other transportation issues such as governance and institutions, policies and planning, laws and regulations, funding and financing, etc. There is a need for research collaboration between industries (e.g., government agencies, local consultants) and universities in the development of complex models, technical and administrative guidelines, and standards and best practices etc. The university-industry collaboration is also needed to identify curriculum needs in the establishment of interdisciplinary degree programs that the nation critically needs.

The collaboration between universities, research institutes, and government agencies is also needed to train and educate agency officials. Furthermore, agencies and local consultants are required to create favorable learning environment to attracts talents and retain them on the job. Government agencies and consultants also need to provide internship opportunities to senior level students so that they get exposed to real world experience. To support research works including compilation and documentation of critical data (e.g., data collections and surveys), each government agency must have to allocate some funds.

ISSUE # 5: GOVERNANCE AND INSTITUTIONS

A large number of government agencies are involved in the Dhaka Metropolitan Area (DMA) with various responsibilities affecting the development of transportation systems and services (see Table 1). With centrally controlled governance system in Bangladesh, all agencies are vertically aligned long respective ministerial line *(Rahman, 2013)*. And, thus none of the local agencies enjoy full autonomy meaning that local agencies cannot make independent decisions with respect to budget and spending, fund generation, and the development of policies

© ASCE 2014

and programs without approval from the central government through respective line ministry. Decisions relating to the infrastructure development projects are made centrally with the help of Planning Commission (PC) that reviews and recommends projects that are in line with the government's socio-economic development goals on a priority basis. All approved projects are funded through fiscal (annual, June-July) budget under the program called "Annual Development Program (ADP)".

Table 1. Selected Government Agencies with Transport Related Responsibilities.

Agency	Key Responsibilities	Ministry Affiliation
DTCA	Transport Planning and Policy Coordination	Communications
RAJUK	Land Use Plan and Housing/Land development	Housing and Public Works
BRTA	Regulation, licensing, Bus Route Permits	Communications
DCC (DNCC, DSCC)	Infrastructure maintenance, and Tax and Fee collections	Local Government, Rural Development and Co-operatives
BRTC	Operates Buses on City Streets	Communications
LGED	Infrastructure Development	Local Government, Rural Development and Co-operatives
DMP	Traffic Control, Management, and Enforcement	Home Affairs

Among the local agencies, the Dhaka City Corporation (DCC), under the Ministry of Local Government and Rural Development (LGRD), is responsible for administering and managing the city properties. In December 2011, the local government (City Corporation) act of 2009 was amended to divide the DCC into two parts: (1) the Dhaka North City Corporation (DNCC) covering the area in the northern part of the city, and (2) the Dhaka South City Corporation (DSCC) covering the area in the southern part of the city *(DNCC, 2014; DSCC, 2014)*.The Local Government Engineering Department (LGED), also under the ministry of Local Government and Rural Development (LGRD), is mainly responsible for the development of infrastructures including roads in rural areas and small towns across the country, and it has a jurisdiction within the Greater Dhaka Metropolitan Area *(LGED, 2014)***.** The Dhaka Transport Coordination Authority (DTCA), previously known as Dhaka Transport Coordination Board (DTCB), was created under an act in 2001 with a view to coordinate the formulation of long range transportation plan, infrastructure development and traffic management activities in Dhaka Metropolitan Area (DMA) and its surrounding areas. It has also given the power to assess and build institutional capacities of various government agencies, though the agency itself is a very weak institute. In 2011, through an amendment to act 2001, DTCB was renamed as DTCA while expanding its jurisdictional boundary to include six districts (e.g., Dhaka, Narayanganj, Munshiganj, Manikganj, Gazipur and Narsingdi) with collective area of 7,440 square kilometers. It has also given additional responsibility to implement regional mass transportation system *(DTCA, 2014)*.

The Bangladesh Road Transport Corporation (BRTC), under the ministry of communication, was created in 1961 under the ordinance No 7. BRTC operates inter-district and regional buses as well as a limited number of buses in Dhaka city *(BRTC, 2014)***.** It also provides truck based nationwide cargo service. Due to the shortage of manpower, BRTC often leases its buses to other private operators to operate. Given its wider obligations at national level and weak institutional setting, BRTC is incapable of leading the public transit service in Dhaka city. The Bangladesh Road Transport Authority (BRTA) was established in 1988. It is the national regulatory agency that ensures safe operations of traffic across the country. It issues vehicle registration and fitness certificates, driver licenses, regulate bus fare, formulates National Land Transport Policy and National Road Safety Strategic Action Plan *(BRTA, 2014; MoF,2013b)*. The traffic department of Dhaka Metropolitan Police (DMP) is responsible for managing traffic and controlling road intersections as well as enforcing traffic laws on city's roadways *(DMP, 2014)*.

As the agencies were created and empowered through acts at different times in the past without giving enough thought, there exist many overlapping and conflicting, yet confusing responsibilities among agencies *(Chowdhury, 2008, Rahman, 2013)*.It is also found that due to significant skill shortage and weak functional departments, the agencies find themselves difficult to lead and fulfill their respective obligations *(Chowdhury, 2008)***.** Furthermore, the agencies seldom coordinate and collaborate with each other horizontally to guide the socio-economic and infrastructure developments *(Jabeen 2013,* though, with the establishment of DTCA, some horizontal collaboration efforts are initiated in the recent years. Given the discussion made above, key recommendations with regards to governance and institution are made below:

- ✓ A fully autonomous body has to be created to govern the Dhaka City with a democratically elected mayor to be its leader such that the city can develop its vision and mission effectively. The city government should be empowered with the authority and capacity to formulate policies and programs with its own budget and revenues, raise funds from a wider tax-base, engage in Public-Private Partnership (PPP) agreements, take loans etc
- ✓ Similarly, all local agencies should be given appropriate autonomy through decentralization of power such that they can also make their respective policies and plans, and funding and spending decisions
- ✓ A regional transit agency (an umbrella organization) has to be created to provide public transportation service in Dhaka metropolitan city while consolidating/integrating all private bus service providers. The agency should be given adequate power to impose tax, engage in non-transportation development project with private sectors, as well as plan, operate, budget, manage, monitor and coordinate with private providers. Both the central and local governments should also commit to provide sustained funds to the agency until it becomes a financially self-sustainable agency
- ✓ A new agency (possibility merging DTCA and RAJUK) has to be created to lead the development of integrated policies on transportation, land use and environment
- ✓ Responsibilities and accountabilities of all agencies need to be clearly defined while eliminating all duplicate and conflicting responsibilities
- ✓ National government needs to take appropriate actions to create powerful agencies, build institutions, and functional departments etc with effective mechanism for coordination and collaboration among agencies

ISSUE # 6: FUNDING AND FINANCING

In Bangladesh, infrastructure projects are planned centrally by the Planning Commission (PC), a central planning agency, and all approved projects are included in the Annual Development Program (ADP) for funding through fiscal budget. In each fiscal year, fund is created to implement all approved projects. The ADP is a consolidated fund comes from both the government and international development partner (e.g., World Bank, Asian Development Bank,

© ASCE 2014

International Monitory Fund etc) sources. The major steps involved in the approval of projects are as follow *(Chowdhury, 2014):*

- ✓ Project ideas/needs are generated from various sectoral plans, five year plan and poverty reduction strategies.
- ✓ Each executive agency closely works with the affiliated ministry in the development of project proposal (DPP)
- ✓ The ministry reviews/assess the DPP
- ✓ The DPP is then send to sector divisions of the planning commission for the evaluation of project
- ✓ Upon recommendation for the approval from the Project Evaluation committee (PEC), the minister for planning approves the project (if the project cost is no more than TK 25 Crore), or Executive Committee of National Economic Council (ECNEC) approves the project (if the project cost is over TK 25 Crore)

However, the ADP funds are very limited and projects are selected based on national priorities rather than local needs and priorities. It has already been proven that such a fund is unsustainable, un-stable, and substantially inadequate for the city as the existing poor transportation systems and services are a clear witness of its consequences. Therefore, other potential funding and financing options need to be considered aggressively**.** In this regard, the government needs to assist the city agencies to implement transportation projects through Public Private Partnership (PPP) agreements as discussed by the author elsewhere *(Chowdhury, 2011)***.** To establish a dedicated fund, viability of targeting high yielding and stable funds such as sales, employment, Value Added Tax (VAT), property as well as other potential tax items need to be considered as suggested by the author elsewhere *(Chowdhury, 2014).*

Given that Bangladesh receives a large amount of expatriates remittance income each year (it was US $12.8 billion in fiscal years 2011-12 *(MoF, 2013b),* the viability of consolidating such a fund (e.g., as bond and/or security deposit) to be used for transportation development purposes need to be looked at. Other potential options for the city government would be to participate in the non-transportation development (e.g., real-estate development in and around transit stations, and along transit corridor) projects and impose some form of taxes and fees as part of transit development such as development impact fees, special district tax etc *(Cervero and Kang, 2011; Medda, 2012; Mathur and Smith, 2013)*. This option could be very promising for the proposed regional transit agency. As there is significant housing shortfall in the city *(REHAB, 2012)***,** partnering with Real Estate and Housing Association of Bangladesh (REHAB) in the development of commercial and residential buildings along transit corridor need to be reviewed as it could offset/minimize the financial risk of transit project.

CONCLUSIONS

This paper addresses issues and opportunities toward the development of sustainable transportation systems for Dhaka metropolitan city. The review of existing transportation systems and services reveals that Dhaka relies on its road based transportation system that is substantial inadequate, unplanned, narrow and poorly maintained. Though, walk and public transportation represent a combined mode share of nearly 50 percent, there exist substantially inadequate pedestrian facilities (e.g., sidewalks and cross walks) and public transportation services. Over the years, the city has grown unplanned allowing unrestricted internal migrations. Currently, there is no coordination between land use and transportation plans. There are

© ASCE 2014

governance and institutional weaknesses; institutions are aligned along ministerial lines with no policy level decision making power, and formal coordination and collaboration responsibilities horizontally with each other. Moreover, institutions are mandated with overlapping and confusing responsibilities. Research and developments to solve transportation problems are nearly absent. The government has very limited funds to improve transportation system under the current Annual Development Program (ADP) based allocations.

The detailed findings and recommendations are included under each of the six issues discussed previously. However, some of the critical recommendations are summarized here. From institutional point of view, Dhaka needs a fully autonomous local government and it should be empowered to engage in Public-Private Partnership (PPP) agreements, raise funds from a wider tax-base, and take loans etc to fulfill its obligations. A fully autonomous regional transit agency is also needed to develop, operate and manage public transit services. The transit agency should be given adequate power to raise funds, impose taxes within the designated transit development areas, engage in non-transportation development project with private sectors, and, coordinate and manage private providers. Another agency is needed to lead the development of integrated policies on transportation, land use and environment. Strong policies and plans are also needed to improve road networks (e.g. defining arterials, collectors and local roads), pedestrian facilities and public transportation systems considering the dwellers mobility and accessibility needs,. There is a need for strong traffic regulations, control and management. Specifically, intersections should be controlled appropriately (e.g., signal, and stop/yield control) while safely accommodating pedestrians. Dhaka needs to develop an affordable mass transportation system while integrating major transit system (e.g., Metro Rail, LRT, BRT, waterborne modes etc as feasible) with feeder routes (e.g., local buses, taxis, 3-wheelers/scooters. rickshaws etc. as feasible) as well as giving pedestrians a high priority in accessing the system. Government should also establish interdisciplinary research and educational programs at universities on the basis of needs.

REFERENCES

BRTA (2008). "National Road Traffic Accident Report 2008." *the Bangladesh Road Transport Authority,* http://www.brta.gov.bd/index.php/road-safety, (March 6, 2014).

BRTA (2014). "Home page of the Bangladesh Road Transport Authority." http://www.brta.gov.bd/, (March 7, 2014).

BRTC (2014). "Home page of Bangladesh Road Transpot Corporation." http://www.brtc.gov.bd/, (March 7, 2014).

Cervero, R. and Kang, CD. (2011). "Bus rapid transit impacts on land uses and land values in Seoul, Korea." *Transport Policy*, Issue 18.

Chowdhury K. (2008). "Land Use Planning in Bangladesh", *AH Development Publishing house*, Dhaka, ISBN:984-8360-020-9

Chowdhury Md. S. (2011). "Public Private Partnership: A Prospective in the Development of Sustainable Transport Infrastructures and Services in Bangladesh." *Proceedings of the first T&DI/ASCE congress*, Chicago, Illinois.

Chowdhury Md. S. (2014). "Funding Road Safety Programs and Projects in Bangladesh." *Proceedings of the second T&DI/ASCE congress*, Orlando, Florida (Forthcoming).

DMP (2014). "Home page of Dhaka Metropolitan Police." http://www.dmp.gov.bd/, (March 1, 2014).

© ASCE 2014

DNCC (2014). "Home page of Dhaka North City Corporation." http://www.dncc.gov.bd/, (March 7, 2014).
DSCC (2014). "Home page of Dhaka South City Corporation." http://www.dhakasouthcity.gov.bd/, (March 7, 2014).
DTCA (2014). "Home page of Dhaka Transport Co-ordination Authority." http://www.dtcb.gov.bd/, (March 7, 2014).
ITE (2009). "Traffic Engineering Handbook." *Institute of Transportation Engineers*, 6th Edition.
Jabeen H. (2013). "Private sector investment decisions in building and construction: increasing, managing and transferring risks: The case of Dhaka." *UNISDR*, Geneva, Switzerland.
LGED (2014). "Home page of Local Government Department." http://www.lged.gov.bd/, (March 7, 2014).
Mathur S. and Smith A (2013). " Land value capture to fund public transportation infrastructure: Examination of joint development projects' revenue yield and stability." *Transport Policy*, Issue 30.
Medda F. (2012). "Land value capture finance for transport accessibility: a review." *Journal of Transport Geography*, Issue 25.
MoC (2009). "Road Master Plan." *Roads and Highways Department*, *Ministry of Communications*, Government of the people's republic of Bangladesh.
MoEF (2012). "Rio+20:National Report on Sustainable Development", *Ministry of environment and Forests*, Government of the peoples republic of Bangladesh, Dhaka, Bangladesh.
MoF (2013a). "Budget Documents 2011-12, 2012-13 and 2013-14." *Ministry of Finance*, Government of the peoples republic of Bangladesh, http://www.mof.gov.bd/en/index.php?option=com_content&view=article&id=183&Itemid=1 (Sep. 28, 2013).
MoF (2013b). "Bangladesh Economic Review 2013." *Ministry of Finance*, Government of the people's republic of Bangladesh.
Muzzini, E. and Aparicio G. (2013). "The Path to Middle-Income Status from an Urban Perspective", *the World Bank*, Washington DC.
Rahman, M. (2013). "Urban Governance and Informal Growth Regulation in Dhaka." *AH Development Publishing house*, Dhaka, ISBN:978-984-90486-8-8
RAJUK (2014). "Home page of RAJUK-Capital Development Authority of Bangladesh." http://www.rajukdhaka.gov.bd/rajuk/webHome, (March 7, 2014).
REHAB (2012). "A Comprehensive Study on the Real estate Sector of Bangladesh." *Real Estate and Housing Association of Bangladesh*, Dhaka, http://www.rehab-bd.org/, (March 1, 2014).
Sultana N. (2013). "Efficiency Analysis of Public Transit systems in Bangladesh: A Case Study of Dhaka City." Masters thesis, *University of Waterloo*, Canada.
Wikipedia (2014). "Dhaka." the free encyclopedia, http://en.wikipedia.org/wiki/Dhaka, (March 3, 2014).
World Bank (2007). "Dhaka: Improving Living Conditions for the Urban Poor." Bangladesh Development Series, *the World Bank*, Paper No. 17.

© ASCE 2014

Flood Control and Stormwater Treatment as Sustainable Groundwater Recharge: 21st Street Improvements in Paso Robles, California

Andy Rowe, PE, LEED AP, QSP/QSD[1] and Larry Kraemer, PE[2]

[1]Cannon, 1050 Southwood Drive, San Luis Obispo, CA 93401; PH (805) 544-7407; FAX (805) 544-3863; email: AndyR@CannonCorp.us

[2]Cannon, 1050 Southwood Drive, San Luis Obispo, CA 93401; PH (805) 544-7407; FAX (805) 544-3863; email: LarryK@CannonCorp.us

Conference Topic: Sustainable Cities

ABSTRACT: (150 words)

Improvements to 21st Street in Paso Robles, California combine drainage improvements with stormwater treatment and groundwater recharge on land that was once a part of the nearby Salinas River. The Complete/Green Street, the first of its kind in Paso Robles, uses bioretention, pervious pavers, open-channel draining, and infiltration channels to clean and capture runoff while minimizing flooding during storm events and preserving the pavement. The newly designed streetscape also improves the overall experience of using the street by adding trees, traffic-calming features, and bicycle lanes. In a region that is currently experiencing a historic water shortage, the 21st Street design provides a model for flood control, urban runoff treatment, and groundwater recharge.

Full Paper

Intelligent stormwater engineering can improve drainage while also achieving advanced levels of sustainable urban runoff treatment and groundwater recharge. Recent enhancements of 21st Street in Paso Robles, California, exemplify the potential to combine drainage and recharge improvement. This street was developed on land that once served as a tributary branch of the nearby Salinas River. Historic runoff from the local Mountain Springs Creek Watershed, along with subsequent development of the urban areas over the course of several decades, had resulted in frequent flooding, poor pavement, and inadequate facilities for bicycles and pedestrian traffic.

Improvements to 21st Street were necessary – not only to address usability and improve drainage, but to provide a valuable recharge of the local groundwater supply. In a region that has recently suffered from drastic water shortage, the latter improvement proved especially important.

To improve the situation, the City of Paso Robles in partnership with the Central Coast Low Impact Development (LID) Initiative and SvR Design Company (SvR) developed a conceptual design for a green/complete street and stormwater enhancement project along a critical stretch of 21st Street. The Complete Street component of the project aimed to reduce traffic speeds with traffic calming devices, shade the street with trees, provide improved bicycle and pedestrian facilities, and promote infill and redevelopment. Drainage and recharge goals included reducing the frequency and severity of street flooding,

© ASCE 2014

increasing groundwater recharge, and improving the quality of stormwater runoff reaching the nearby Salinas River.

MOUNTAIN SPRINGS CREEK WATERSHED

The water table in North San Luis Obispo County, California, known as the Paso Robles Basin, has diminished significantly in recent decades. The western portion of the Basin includes the 1,200-acre Mountain Springs Creek Watershed, which provides water to the city of Paso Robles.

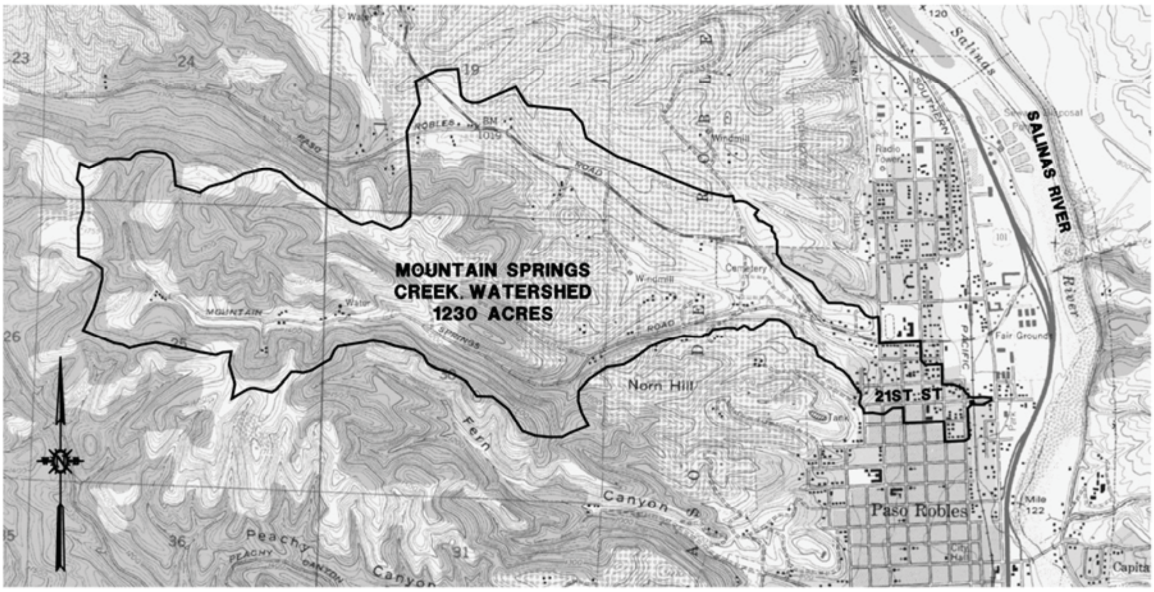


Figure 1. Mountain Springs Creek Watershed.

A major population and commerce center in the area, Paso Robles is too familiar with the effects of drought and water shortage. According to the 2011 Paso Robles Groundwater Management Plan,

> *Groundwater levels in the western portion of the Paso Robles Basin have declined in excess of 70 feet since 1997 during a period when precipitation was just slightly less than the to the long-term average annual precipitation. … The continuing decline suggests that … the rate of extraction exceeds the ability of the basin to recharge the area.*

Figure 2 below shows the drastic depletion of groundwater resources in the City of Paso Robles from 1997 to 2009.

© ASCE 2014

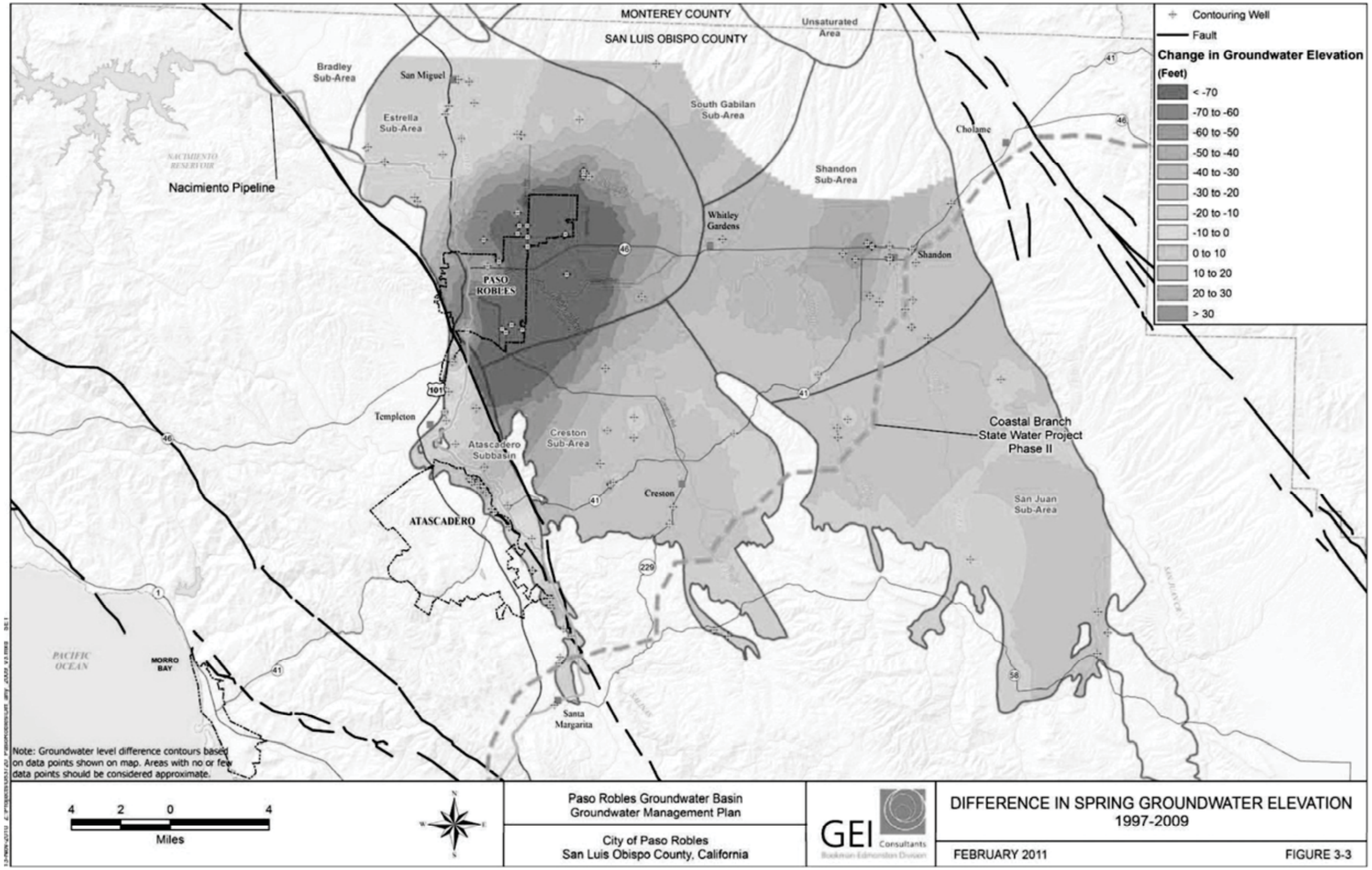


Figure 2. Difference in Spring Groundwater Elevations, Paso Robles Basin, 1997 to 2009.

© ASCE 2014

21ST STREET DESIGN – A LOCAL PROTOTYPE FOR COMPLETE AND GREEN STREETS

For decades, the City of Paso Robles had planned and built wide roadways that facilitated vehicle traffic. Vehicles dominated these streets and discouraged people from walking and bicycling. Vast areas of impervious paving had led engineers to design storm drain systems that conveyed runoff away from the street as fast as possible. As a result, these streets have limited function.

As the first Complete/Green Street in Paso Robles, the 21st Street project was a fundamentally different street design – a paradigm shift. The new 21st Street features a narrower roadway in order to calm traffic and de-emphasize vehicles. The design envisioned a street with multiple functions: a place to walk, ride bicycles, do business, control stormwater runoff, and interact with the community. The project not only provides a local example of a green street, but also provides generic green street standards that will be incorporated into the City of Paso Robles' Engineering Standards. The Central Coast Low Impact Development Initiative will share these generic green street standards with other Central Coast municipalities and encourage them to adopt them as standards.

The 21st Street improvements were engineered to combine bioretention for treatment of the initial stormwater flush with open-channel flow for larger runoff. Figure 3 shows a bird's-eye view of several of this project's features, such as pervious pavers and bioretention areas, which were engineered specifically to improve drainage and increase recharge.

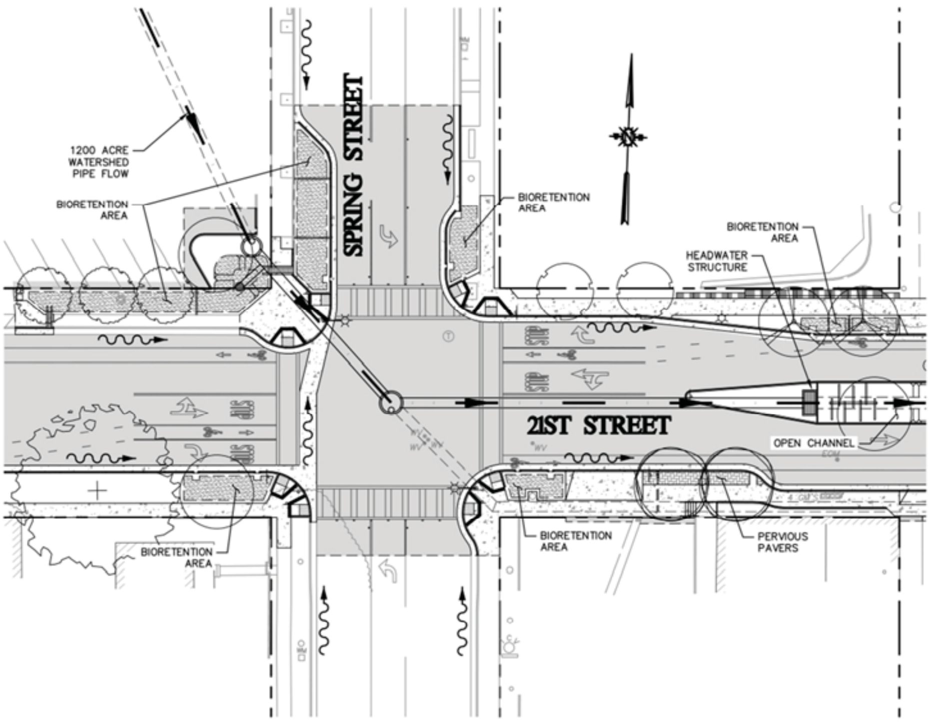


Figure 3. Improvements at the Intersection of 21st and Spring Streets in Paso Robles.

© ASCE 2014

Figure 4 below provides a cross section of 21st Street detailing both the Complete and Green Street components of the project, including the 15-foot daylighted median drainage channel bisecting the street.

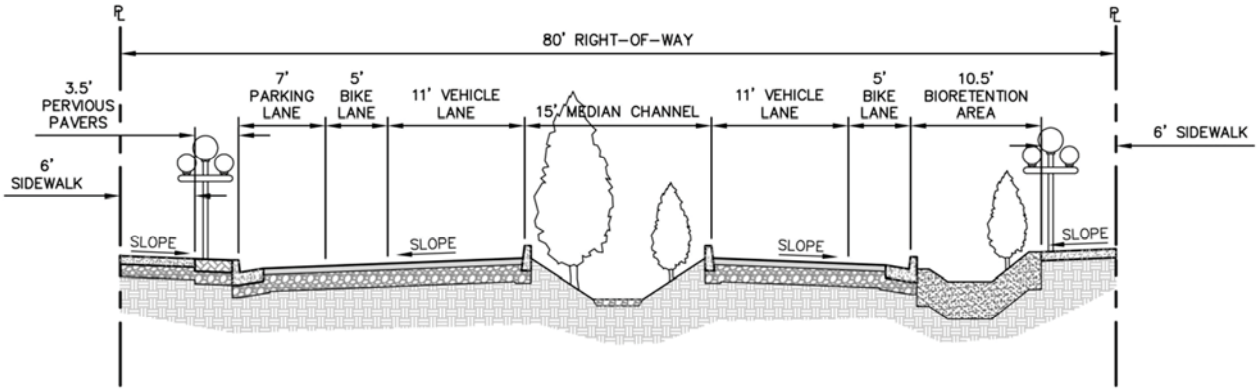


Figure 4. 21st Street Design Cross-Section.

BIORETENTION

The 21st Street project specifically addressed surface recharge elements highlighted in the Paso Robles Groundwater Basin Management Plan. According to the Plan,

> *Most of the groundwater recharge in the Paso Robles Basin results from the infiltration of precipitation. Surface recharge potential in the Paso Robles Basin is a function of soil type. As such, the surface soil conditions are one of the primary factors affecting groundwater recharge in the Paso Robles Basin.*

The stormwater engineering team reviewed green street standards in Portland and Seattle and contacted LID design professionals to understand and design green street infrastructure to function well over the long term. These efforts resulted in the implementation of deepened curbs and impermeable liners to prevent the road base section from becoming saturated and causing asphalt degradation; depressed gutters and cobble at curb cuts to ensure long-term clear flow paths into the bioretention areas; and check dams to increase ponding volumes. The project eliminated the use of filter fabric in bioretention areas, which have been recently shown to impede infiltration in the long term.

Bioretention areas were placed strategically at the edges of the street in order to achieve treatment of first stormwater flush. Stormwater run-on to 21st Street from the Mountain Springs Creek Watershed is relatively clean. The project provides separation of the clean water from the polluted urban runoff by directing stormwater from the Creek Watershed to the median channel, while directing urban runoff to the bioretention areas. In this way, the clean water does not mix and dilute the polluted water, allowing for a higher level of pollutant removal in the bioretention areas.

© ASCE 2014

Caltrans methods for water quality volume and flow were used to determine the treatment goals, which are comparable with the 85th-percentile storm event. For volume capture, this corresponded to a 0.28-inch unit basin storage volume and a 0.18-inch/hour water quality flow rate. Depending upon infiltration test results, it was found that some bioretention areas were designed with a more efficient use of space by volume capture, whereas others with the highest infiltration rates were designed with more efficient use of space by water quality flow rate.

Providing treatment to the stated goal level for 21st Street itself is not difficult because 21st Street funnels stormwater runoff from many blocks to the north and south. However, treatment of the entire 31-acre urban surface runoff watershed to meet treatment goals was not possible. When accepting runoff from large tributary areas, bioretention areas were enlarged to the greatest extent possible given other site constraints. It is the hope that future reconstruction of streets with runoff tributary to 21st Street will provide their own treatment in the future to help meet these goals. The newly designed 21st Street can provide more than 6,000 cubic feet of stormwater treatment during storm events.

Curb bulb-outs at intersections are typical locations where bioretention areas are provided. These are areas where parking is removed and the curb line is transitioned to the edge of the parking lane. Parking is not desired at intersections due to sight distance considerations. Pedestrian safety is enhanced by the establishment of a shorter crossing distance, and space is provided for bioretention.

Where the existing sidewalks attached to the curb line are mostly in good condition, the project provided reverse sidewalk underdrains to route stormwater from the curb line to behind the sidewalk. This allows for the preservation of existing materials and provides a good solution for retrofit type designs.

The Green Street research also led to the application of generous correction factors to the field-tested infiltration results. This gave the engineering team the confidence to design 21st Street for bioretention without underdrains once the estimated long-term infiltration rates of the underlying soils were determined. The lack of underdrains – structures commonly placed in bioretention areas for water treatment that prevent stormwater from seeping into the underlying soil and, consequently, the groundwater supply – allows stormwater to soak into depressed areas of the landscape and re-enter the water table. Deepened curbs and impermeable liners were provided to prevent asphalt base saturation and improve road longevity. Trench dams were provided to prevent utility trench saturation and migration of stormwater into utility pipes. For most bioretention areas, overflow was provided out the lower curb cut. Installation of an overflow to an underground storm system was deemed an unnecessary cost, as it would have meant the installation of a new storm sewer main for just this purpose. Moreover, stormwater flow for the design storm event does not produce an excessive roadway spread.

© ASCE 2014

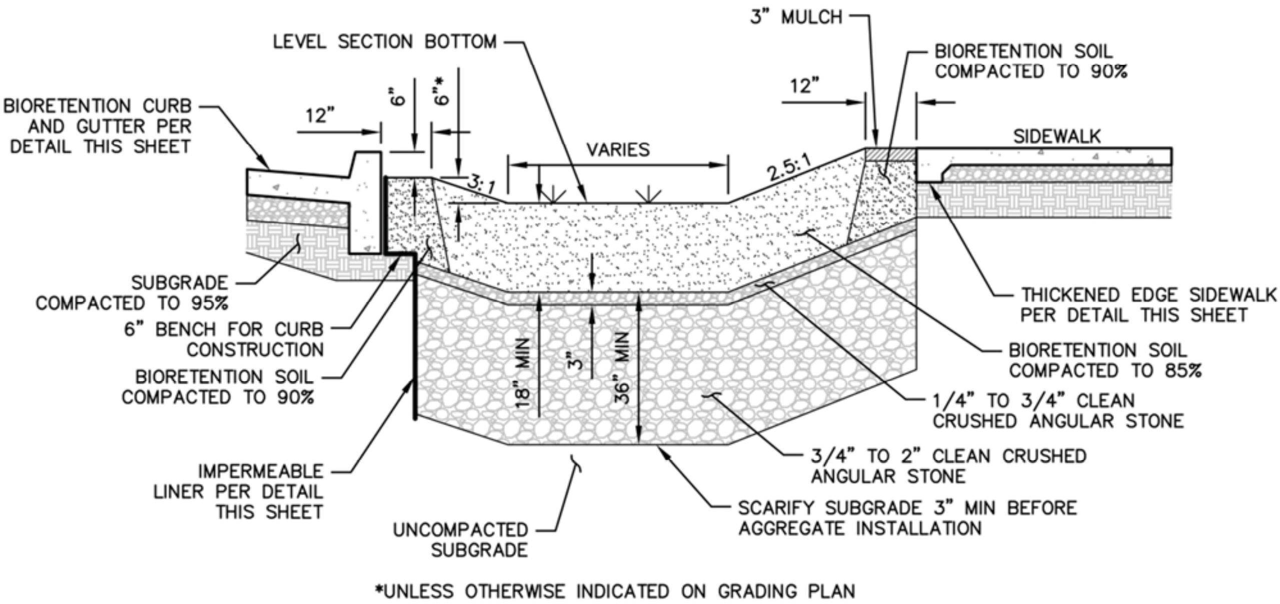


Figure 5. Cross-Section Example of Bioretention Design on 21st Street.

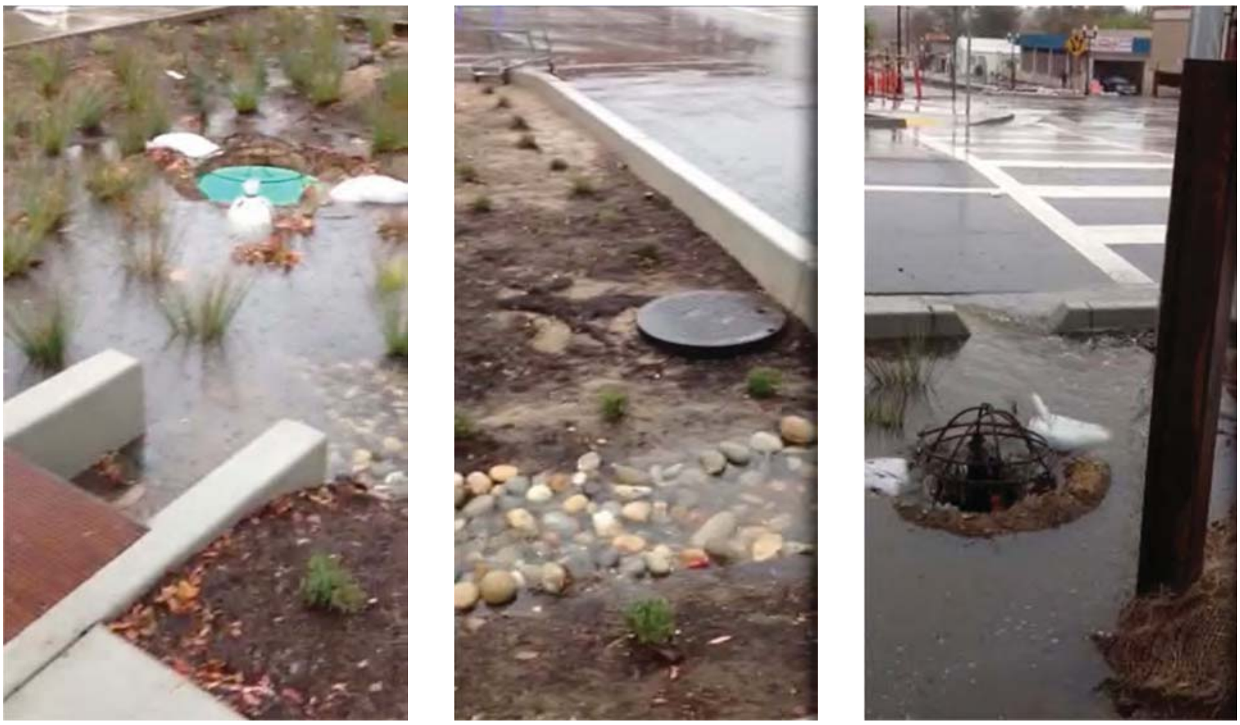


Figure 6. Three Examples of Urban First Flush Drainage into Bioretention Swale – 21st Street, Paso Robles, California.

The United States Environmental Protection Agency (EPA) identifies urban runoff pollutants to include sediment, oil, grease from motor vehicles, pesticides and nutrients

© ASCE 2014

from lawns, viruses and bacteria from pet waste, and thermal pollution from dark surfaces. These pollutants can harm fish and wildlife, kill native vegetation, foul drinking water, and make recreational areas unsafe and unpleasant. The 21st Street project's bioretention design uses soil media, plants, roots, and microbes to achieve the desired pollutant removal and thereby help address water quality issues in the Salinas River.

The top 18-inch soil layer within the streetscape of 21st Street physically traps particles and strains them from the stormwater. Bioretention systems like those designed in this project can achieve a high degree of pollutant removal for common urban pollutants such as those designated by the EPA. The uppermost mulch/soil layer in bioretention systems has been found to provide the greatest pollutant uptake and degradation. Metals for example, bind easily to the organic matter in the top layer of bioretention soil media.

Along with the upper soil levels, drought-tolerant plantings in the landscape areas both prevent erosion and provide treatment of the storm runoff through biological processes. Consequently, with the first flush treated and infiltrated, stormwater from 21st Street that does make its way to the Salinas River is cleaner than it was before.

PERVIOUS PAVERS

The 21st Street design also incorporated pervious pavers in pedestrian areas (see Figure 6 below).

Figure 7. Pervious Pavers.

These concrete pavers were purposely set with built-in gaps between them, which created room for stormwater to seep into the ground. Note that Figure 6 shows the gaps placed

© ASCE 2014

between the pavers prior to the placement of joint filler. Consisting of small stones, joint filler allows water to permeate into the gaps while acting as a screen for street litter and other large objects.

OPEN-CHANNEL DRAINAGE AND INFILTRATION CHANNELS

Open-channel drainage design on 21st Street allows for conveyance of large-scale stormwater flow. The outfall structure to the median channel incorporates a large sump for sediment capture. Energy dissipation features are provided at median outfall and box culvert outfalls using rock riprap and reclaimed railroad rails. A temporary orifice plate was designed to limit flow to the median channel during plant establishment. This plate can be removed upon the determination that plantings can handle the increased flows. Open channels running down the middle of the street are connected via box culverts at intersections to allow for the passage of street traffic. Placed in lieu of drain pipes, these channels allow for even more water infiltration into the landscape – and the local water supply.

In one location, the drainage channel contains an infiltration trench for yet another level of drainage and groundwater recharge. The engineering process included infiltration testing aimed at locating areas with the sandiest – and therefore most permeable – soils beneath the streetscape. Placed in these areas of superior infiltration, the trenches contain perforated piping surrounded by clean rock. This makeup allows for the storage of large quantities of stormwater as it infiltrates into the underlying soil. The project also incorporates carefully engineered soil mixes for the bioretention areas, designed to infiltrate at a dependable rate that is just slow enough to provide necessary treatment and fast enough to allow a large volumes of runoff to be infiltrated rather than simply running off.

© ASCE 2014

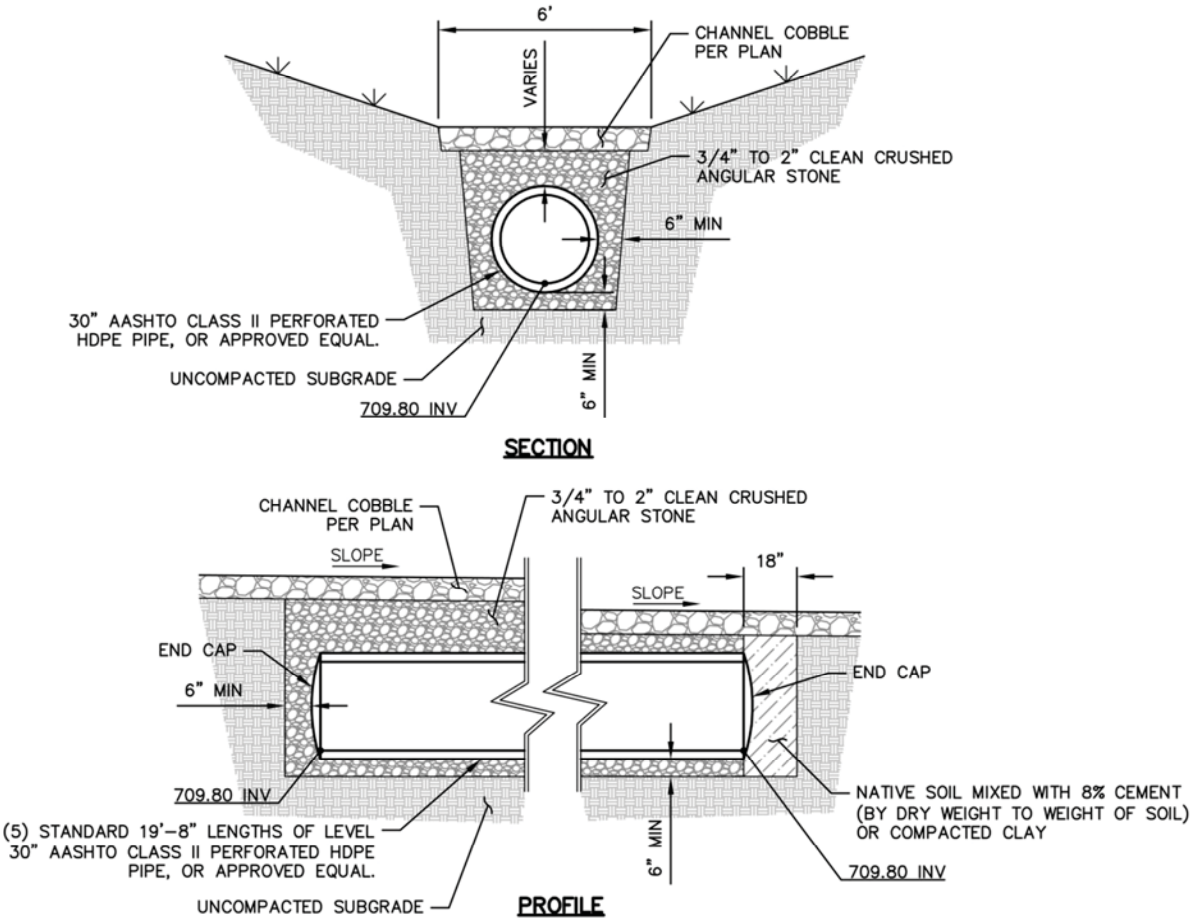


Figure 8. Section and Profile of Infiltration Channels.

CONSTRUCTION, OUTREACH, AND REPERCUSSIONS

The project's bioretention areas can hold more than 46,000 gallons of stormwater at a time. An even greater volume will be infiltrated during each storm event that exceeds the 85th percentile.

The project cost is approximately $2.5 million, with $1 million of grant funding. The construction period began in spring 2013 is and scheduled for completion in spring 2014.

Public workshops were held during the planning process, and the design was developed incorporating the feedback obtained.

© ASCE 2014

Figure 9. Construction of Drainage Trench on 21st Street (Left); Drainage Trench During Storm Event (Right).

All told, the 21st Street Improvement Project provides some relief to a massive flooding issue while not only diverting stormwater into the local groundwater supply but also cleaning the water as it enters the groundwater table. In effect, it promotes sustainable drainage and groundwater recharge by bringing the historic drainage channel in line with its original, more natural form.

REFERENCES

Sneed, David. (2013). "Deep Trouble in the North County." *The Tribune*, June 16, Local News

City of Paso Robles. (2011). *Paso Robles Groundwater Basin Management Plan*. Paso Robles, California

United States Environmental Protection Agency. (2003). *Protecting Water Quality from Urban Runoff*. Washington, DC

© ASCE 2014

Meeting the Infrastructure Challenges of African Cities

Daniel Hoornweg[1], Katherine Sierra[2], Michael Sanio[3], and Kim Pressnail[4]

[1] Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, ON, L1H 7K4; PH (905) 721-8668, Ext. 5560; FAX (905) 721-3046; email: daniel.hoornweg@uoit.ca
[2] Global Economy and Development Program, The Brookings Institution, 1775 Massachusetts Avenue, NW Washington, DC 20036; email: ksierra@brookings.edu
[3] Sustainability and International Alliances, American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191; PH (703) 295-6116; FAX (703) 295-6319; email: msanio@asce.org
[4] Department of Civil Engineering, University of Toronto, 35 St. George Street, Toronto, ON, M5S 1A4; email: pressna@ecf.utoronto.ca

Abstract

Today, less than ten percent of the world's urban population lives in African cities. By the end of this century that ratio is on track to swell to more than a third of the world's total (a growth of 2.2 billion urban residents). Today, just seven of the world's 100 largest cities are in Africa, by 2050 that will increase to 21, and by 2100, 40 of the world's 100 largest cities are expected to be in Africa and five of the world's largest ten cities will be in Africa, each with more than 50 million residents. In addition to the $20 trillion needed over the next 40 years to build the cities for more than 2 billion people, by 2040 Africa also needs the equivalent of about 600,000 engineer graduates per year to design and manage the services underpinning these cities. When assessing Africa's urbanization trends and the acute need for finance, stability of macro-economic and social conditions, institutional strengthening, efficient urban form, and capacity – this paper asserts that a critical need is capacity, especially domestic engineering capacity. The scale of Africa's capacity needs will necessitate new models of collaboration and urban management.

Background

There is a severe shortage of engineering capacity in Sub-Saharan Africa. At the World Summit for Sustainable Development in Johannesburg in 2002, WFEO spearheaded the development of the Africa Engineers Protocol concept of sustainable engineering as a prerequisite for sustainability. A guidebook was prepared and launched at the WFEO World Engineers' Week in Buenos Aires in October 2010.

© ASCE 2014

A key aspect of WFEO's building good practice of capacity for sustainable development includes six integrated pillars: (i) individual; (ii) institutional; (iii) technical; (iv) decision making; (v) finance and funding; (vi) resources, equipment, tools and supplies (Figure 1).

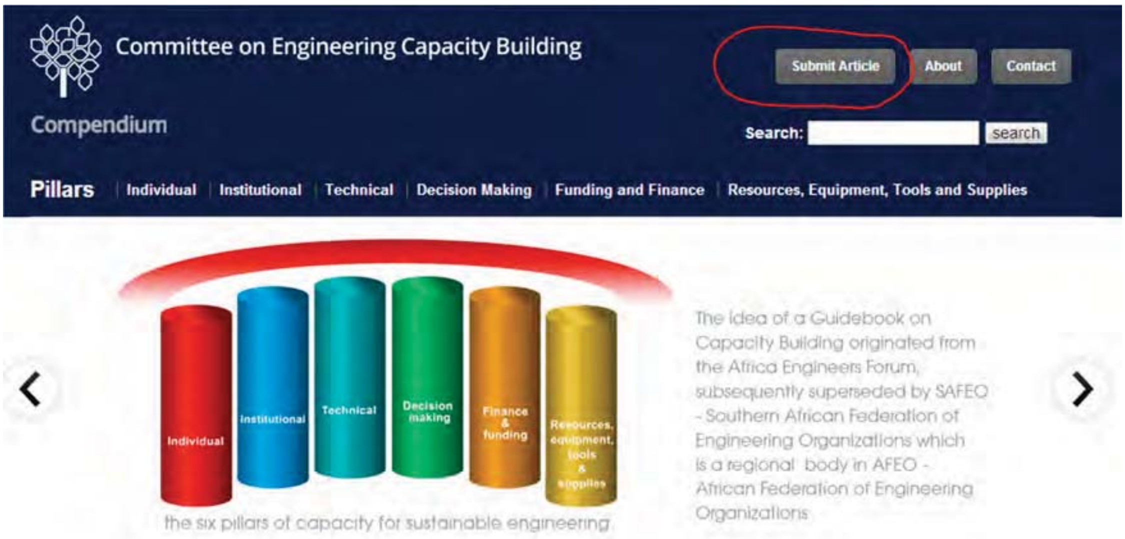


Figure 1. The Six Pillars of Capacity for Sustainable Development, WFEO.

The nexus of sustainability, human development, and the application of knowledge and technology through engineering capacity is shifting to Sub-Saharan Africa. Homo sapiens originated in Africa, dispersed across the planet filling almost every geographic niche. With the advent of agriculture and trade, rural populations coalesced and urban centers grew. The last 100 years saw urban populations increase globally from about 25% to today's greater than 50% urbanization rate. This head-long rush to urbanize will culminate in Sub-Saharan Africa. Urban populations drive the world's economy and are responsible for almost all the world's wealth – and corresponding pollution. The next 75 years will see the world's last remaining region – Sub-Saharan Africa – urbanize from today's less than 30% to more than 70%. Today, two of the world's largest 25 cities are in Africa and by the end of this century that will increase to 16 (Hoornweg and Pope, 2014 - see Figure 2).

Today, roughly two out of three sub-Saharan Africans – around 600 million people – have no access to electricity. Approximately the same number remains without mobile telephone subscriptions. Although the majority of these are rural residents these service deprivations are moving quickly to urban areas. Africa has the world's fastest growing un-serviced urban slums.

© ASCE 2014

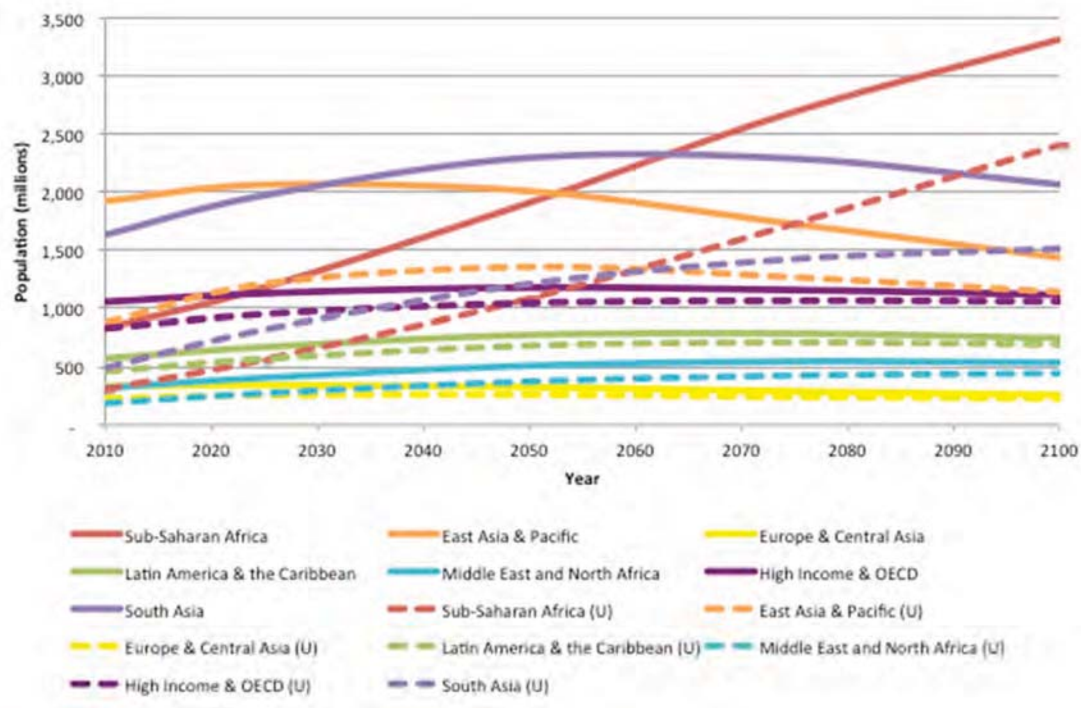


Figure 2. Total and Urban Populations, 2010 – 2100.

One of the largest challenges ever faced by humanity is to build the cities of Africa. The shape and growth of African cities is critical – locally, regionally and globally. Asia, with its burgeoning urban population, rightfully has the attention of many of today's policy advisors and business development officers. However, long-term sustainable development will largely be determined by Africa's cities.

The Shape of Cities to Come

Despite conclusive evidence on the benefits of urban density for quality of life, reduced infrastructure costs (capital and operating), reduced GHG emissions, and shorter commute times (see Figure 3), population density in Africa's cities is, by and large, actually declining. Highlighted in Figures 4, 5 and 6 for Addis Ababa, Nairobi, and Johannesburg, respectively, density in African cities in declining by about 2% per year.

Sub-Saharan Africa's development challenges are exacerbated by the large-scale adaptation requirements expected from climate change. Climate forecasts anticipate that the African continent will be most impacted by a warming world (WDR 2009). Africa's climate impacts will add to the continent's already serious water scarcity, as well as threaten coastal cities, food supply, and likely add to the region's already burgeoning environmental refugees. Several of the world's soon-to-be largest and already fastest growing cities are coastal cities in Africa, for example, Lagos and Dar es Salaam. Key infrastructure like roads and power stations tend to 'lock-in' cities; their shape and corresponding resource use is determined by the 'bones of the city' built in the beginning. The street patterns in Manhattan and downtown London are more than 100 years old, yet they determine today's traffic flow, both for pedestrians and vehicles.

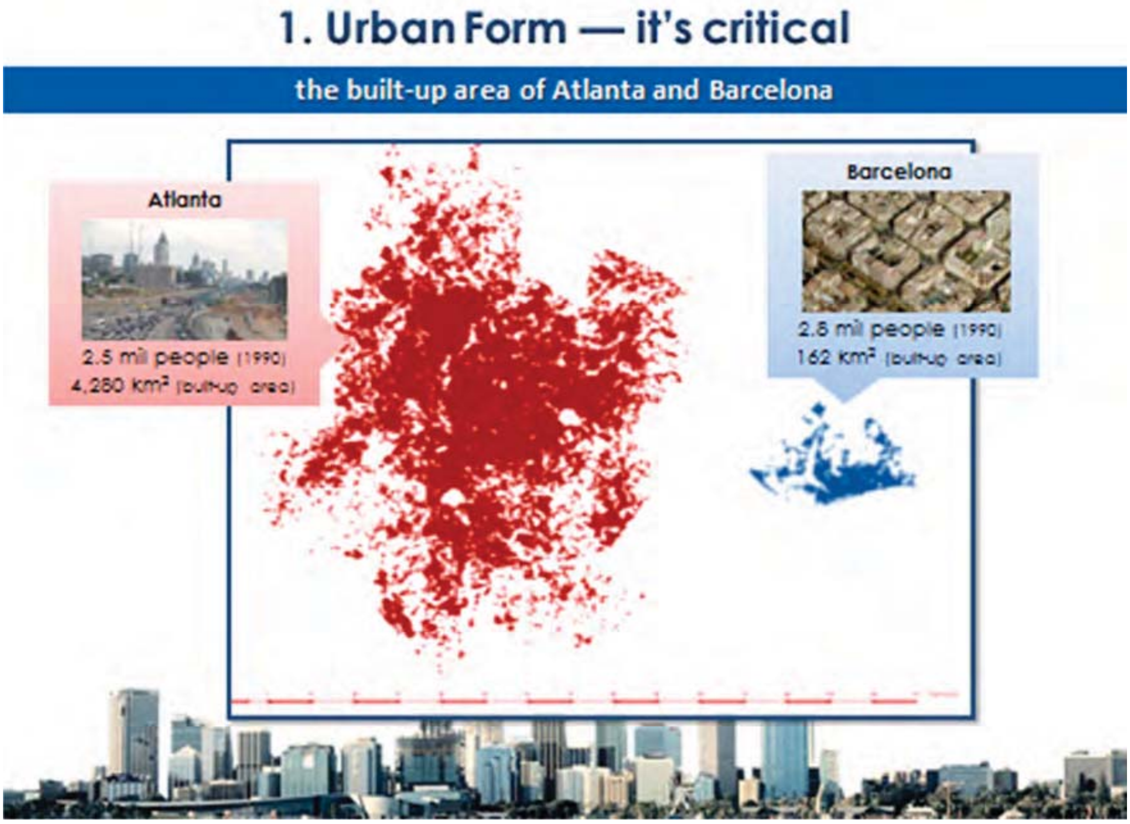
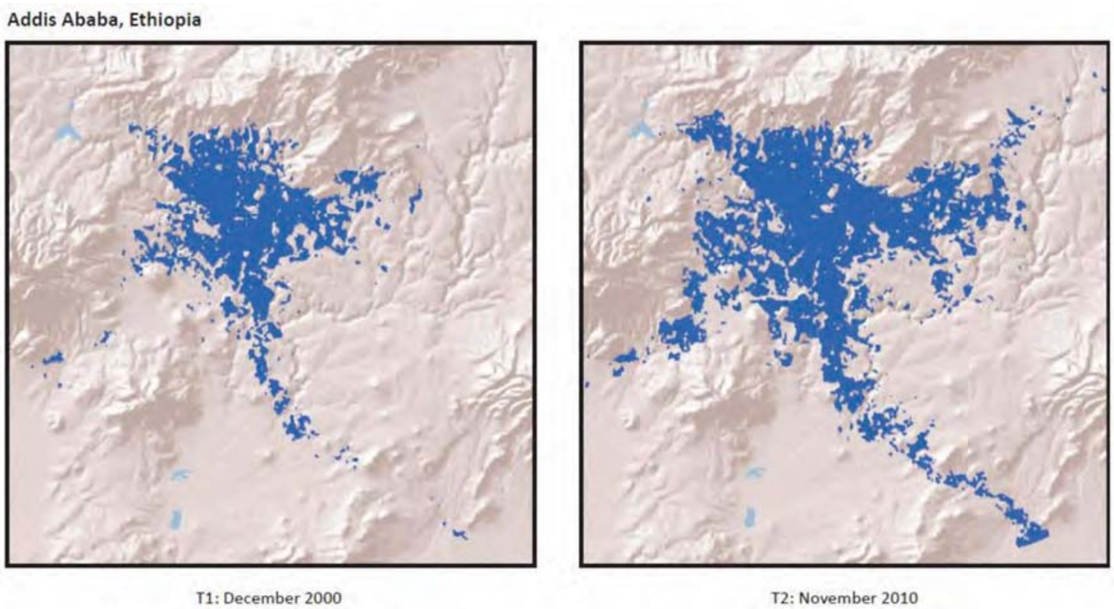
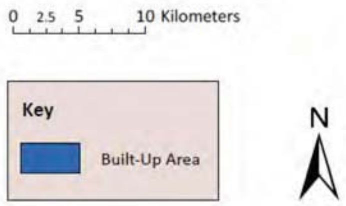


Figure 3. A Comparison of Atlanta (approx. 23 t/capita CO_2e) versus Barcelona (approx. 4 t/capita CO_2e).

Africa's potential urban growth is enormous. By 2100, the cities of Lagos, Kinshasa, Dar es Salaam, Khartoum, Niamey, Nairobi, Lilongwe, Blantyre City, Cairo, Kampala, Lusaka, Mogadishu, Addis Ababa, N'djamena, Kano, Sana'a, Ibadan, Luanda, Bamako, Maputo, Ouagadougou, and Antananarivo are all expected to have populations in excess of 20 million. With a combined population of more than 900 million (Lagos – to become the world's largest city, Kinshasa, Dar es Salaam, Khartoum, and Niamey are on course to each have more than 50 million residents) these 22 cities warrant focused global attention as they will set the stage for the African continent, and the world (Hoornweg and Pope, 2014).

© ASCE 2014

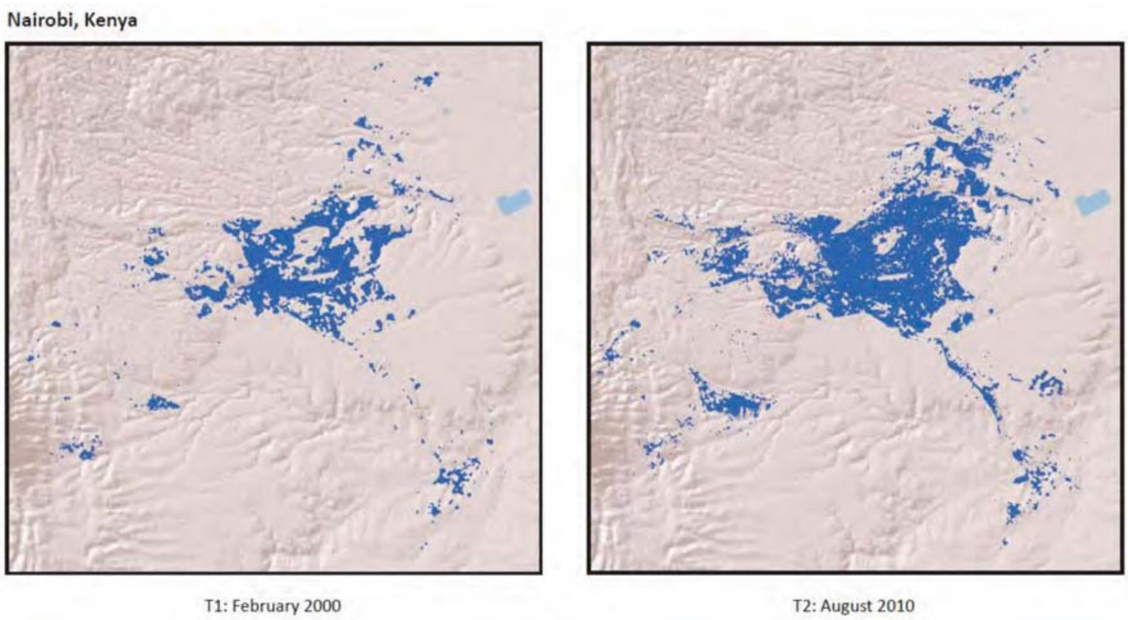


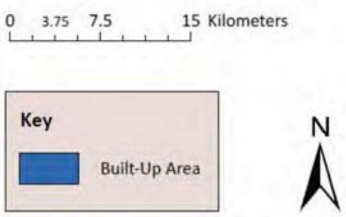


Measure	T_1	T_2	Annual Change (%)
Population	2,376,189	2,929,626	2.12
Built-Up Area (sq km)	121.75	224.51	6.31
Average Density (persons/sq km)	19,517	13,049	-3.95
Built-Up Area per person (sq m)	51.24	76.63	4.11

Figure 4. Spatial Growth of Addis Ababa, Ethiopia.

© ASCE 2014

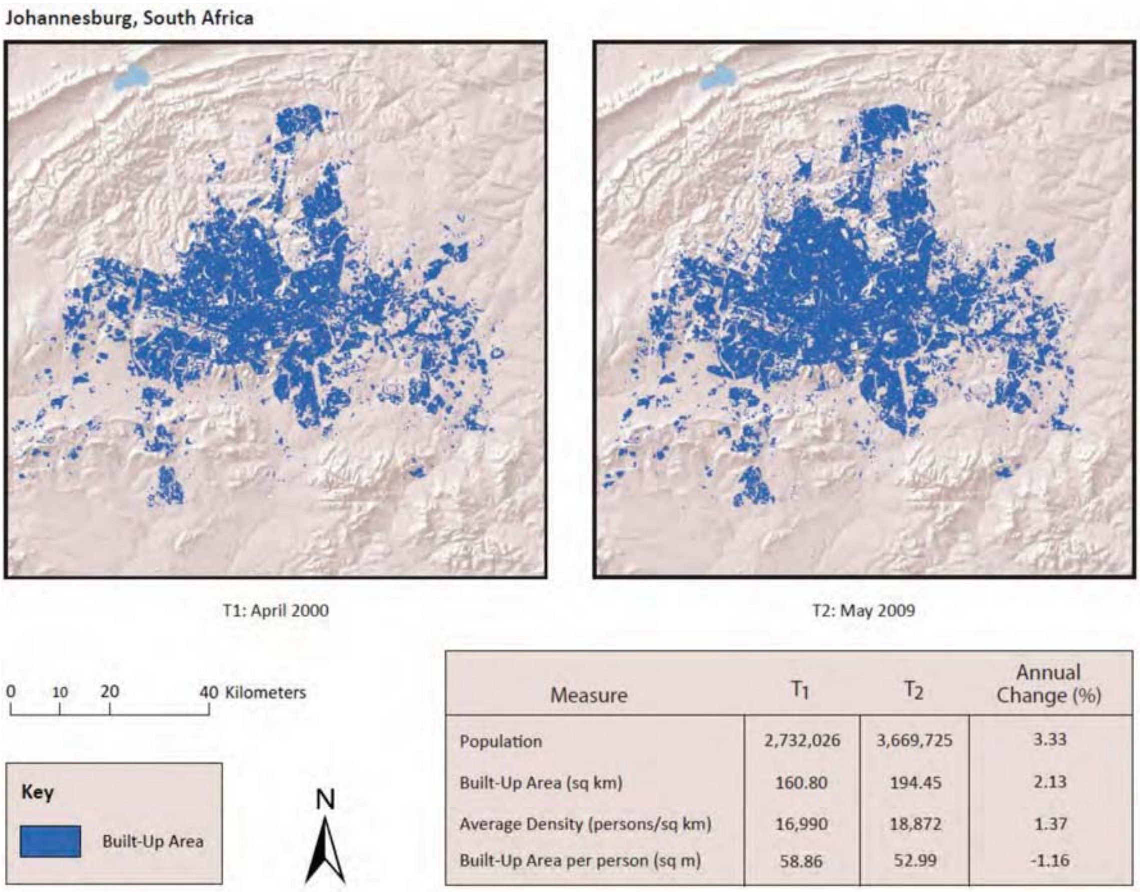




Measure	T_1	T_2	Annual Change (%)
Population	2,230,079	3,523,349	4.68
Built-Up Area (sq km)	94.33	186.50	7.05
Average Density (persons/sq km)	23,641	18,892	-2.22
Built-Up Area per person (sq m)	42.30	52.93	2.27

Figure 5. Spatial Growth of Nairobi, Kenya.

© ASCE 2014



Measure	T_1	T_2	Annual Change (%)
Population	2,732,026	3,669,725	3.33
Built-Up Area (sq km)	160.80	194.45	2.13
Average Density (persons/sq km)	16,990	18,872	1.37
Built-Up Area per person (sq m)	58.86	52.99	-1.16

Figure 6. Spatial Growth of Johannesburg, South Africa.

Building Cities (and Capacity)

Conservatively, the number of engineering students in Africa, using similar staffing levels from OECD economies, will need to exceed 10,000,000 by 2050[1]. Today, there are likely less than 100,000 engineering students in SSA (70% in South Africa). Increasing these numbers 80-fold, as required in some countries, is as daunting a task as financing this city growth. The UK, for example, has a population per engineering graduate of 1,100, while Cameroon, Ethiopia, Swaziland, and Mozambique have average populations greater than 81,000 per engineering graduate (UNESCO Engineering Report 2010).

A comprehensive review of engineering capacity was recently undertaken by the joint Africa-UK Engineering for Development Partnership (Royal Academy of Engineering) – 'Engineers for Africa: Identifying engineering capacity needs in Sub-Saharan Africa'

---

[1] Based on the UNESCO Engineering Report that estimated approximately 6.5 million students enrolled in tertiary level "engineering" education for all OECD countries in 2006.

© ASCE 2014

(summary Report, October 2012). The extensive report's key conclusions and recommendations:

- a lack of domestic engineering capacity is a serious impediment to economic growth;
- greater recognition of the socio-economic benefits (capacity building) associated with infrastructure is needed;
- countries that rely on foreign engineering expertise need to develop strategies to build local capacity (through those investments);
- international agencies need to invest in capacity needs research;
- joint programme capacity reviews need to be undertaken;
- investments in science, engineering, technology, and infrastructure need to include capacity building components;
- procurement practices should optimize sources from domestic suppliers; and
- governments need to invest in national engineering capacity needs research.

Africa, and Sub-Saharan Africa in particular, has the lowest regional level of domestic graduate and student engineers. The backlog will take decades to fill, all while cities undergo the fastest urbanization and growth rates ever. Universities and professional engineering associations are responding, such as the Africa-UK Engineering for Development Partnership. The pace of these initiatives will undoubtedly increase as capacity demands grow. Coordination and customized national-regional programs should yield significant efficiencies (WFEO 2013).

As US Senator Monaghan said, "If you want to build a great city, build a great university and wait 200 years." Africa can not wait 200 years, however as most of the larger cities already have universities with engineering faculties, there is likely to be a symbiotic and supportive growth between key African cities and their local universities. Engineering faculties will likely take on a more robust roll of local city building – especially within a global context as capacities, and opportunities for faculty and student exchanges increase.

Building and Locking-In Sustainable Development

Much of Africa's urban infrastructure does not yet exist. Although current growth trajectories indicate a worrisome trend (i.e., city extent growing 50% faster than population growth), significant benefits can accrue if a more sustainable growth trajectory is pursued. Local quality of life (e.g., air pollution, traffic congestion); scale, and cost, of infrastructure needs; economic development; and corresponding domestic capacity will all benefit from a more sustainable (i.e., compact) city form. If Sub-Saharan Africa's cities follow two broad routes to urbanization (e.g., Barcelona or

© ASCE 2014

Atlanta in Figure 3), the difference in global greenhouse gas (GHG) emissions would be in excess of 3 billion tonnes/year[2] (about 30% of today's global emissions).
The scale and pace of Sub-Saharan Africa urbanization will have global impacts as materials, economic development, capacity (supply and demands for qualified personnel), and local and global environmental effects, are all impacted by the three-fold growth expected in Africa city-populations. Urban life in London, for example, is largely influenced by the way the streets were laid out more than 100 years ago. The great fire of London still impacts today the layout of city blocks, streets, and the underground. US cities for example will probably take another 30 – 50 years to overcome original land use plans that highly favored automobile dependence (with associated larger houses and overall energy use).

The engineering profession plays a key role in the shape and management of cities, and by direct extension the pace toward sustainable development. Sub-Saharan Africa's cities present a global challenge[3]. Engineers need to act collegially and cooperatively as a profession to bring about more sustainable cities while also working within competitive private sector and national pressures. The need and opportunity for these shared efforts are by far greatest in Sub-Saharan Africa, which should likely bring about a new era of technical cooperation.

Discussion

Sub-Saharan Africa's infrastructure need is an enormous challenge – financing, local and global ecosystem impact, and staffing (and governance) capacity of those needed to build and manage the cities and the infrastructure. The scale of the demands also present an enormous opportunity. A task this large requires new thinking, new partnerships, and new models of cooperation and professionalism. Hyperbole aside, Africa's cities are likely the largest determinant of future sustainable development. To a large extent, the development of African cities will follow from Asia's larger cities that will begin to wane in population around 2040-2050 in East Asia and about two decades later in South Asia (Table 1).

Many countries in Africa consistently place in the bottom quintile for quality of life, governance, and transparency ratings. Africa is expected to be among the hardest hit geographies as regional and global climates change, and coastal cities and drought-sensitive areas will be particularly threatened.

---

[2] Based on 2 billion new urban residents emitting an additional (incremental) 15 tonnes/cap-year.
[3] The challenge requires both an enormous capacity increase in engineering support as well as an equitable (historically contextual) and immediate massive effort at city building – infrastructure and finance to support this infrastructure.

© ASCE 2014

Table 1. Change in City Ranking this Century.

Rank of the World's 25 Largest Cities in the 21st Century

(Metropolitan Areas)

	2010	2050	2100
1	Tokyo	Mumbai	Lagos
2	Mexico	Delhi	Kinshasa
3	Mumbai	Dhaka	Dar es Salaam
4	Beijing	Kinshasa	Mumbai
5	Sao Paulo	Kolkata	Delhi
6	**New York**	Lagos	Khartoum
7	Delhi	Tokyo	Niamey
8	Shanghai	Karachi	Dhaka
9	Kolkata	**New York**	Kolkata
10	Dhaka	Mexico	Kabul
11	Buenos Aires	Cairo	Karachi
12	Karachi	Manila	Nairobi
13	**Los Angeles**	Sao Paulo	Lilongwe
14	Cairo	Shanghai	Blantyre City
15	Rio De Janeiro	Lahore	Cairo
16	Manila	Kabul	Kampala
17	Moscow	**Los Angeles**	Manila
18	Osaka-Kobe	Chennai	Lusaka
19	Istanbul	Khartoum	Mogadishu
20	Lagos	Dar es Salaam	Addis Ababa
21	Seoul	Beijing	Baghdad
22	Paris	Jakarta	**New York**
23	Jakarta	Bangalore	N'djamena
24	Guangzhou	Buenos Aires	Kano
25	**Chicago**	Baghdad	Sana'a

From: Hoornweg, Corporate Knights, 2013

© ASCE 2014

Unlike the standard practice between businesses, a highly competitive approach to engineering staffing and capacity between cities will not optimize infrastructure development and urban management as deficiencies in one city may have dramatic impacts on other cities. A more collegial and cooperative approach is necessary. The expected shortfall of more than 500,000 domestic graduate engineers per year necessitates shared access to technical experience, wide-spread mentorships, and likely a greater reliance on technological support, and remote facilities monitoring, (e.g., new web-based SCADA systems).

In addition to an increased engineering capacity, African cities will need to build more robust partnerships with local communities. The public will need to be a strong ally of urban development and management personnel (and local politicians) as robust social licenses (and cooperation) will be needed in areas such as population density increases, basic service provision (e.g., how and when to put out garbage), adherence to traffic codes, and municipal finance.

At the behest of their political and corporate leaders, civil engineers built most of today’s cities. By and large, these cities use too many resources, generate too much pollution (e.g., GHG emissions and local air pollution), and are often congested, unsafe, and can act as a drain on economic development. True, these same cities generated most of today’s wealth, but it is clear that if these cities are to double in size again in the next 35 years (mostly in Asia), and again in the following 35 years (mostly in Africa), the planet’s assimilative capacity will be over-taxed. Local and global challenges, such as water scarcity and climate change, already threaten today’s cities. The world’s engineers are being called to build better cities, to abandon much of the 20th century practices, and lead – probably with African as a key focus – to a new 21st century civil engineer. Key aspects of this 21st century engineer will be resource minimization, a stronger social contract, much greater access to energy, and cities that more closely model natural systems.

References

Hoornweg, D. and K. Pope, 2014. Population predictions of the 101 largest cities in the 21st century. Global Cities Institute

Hoornweg, D. 2013. Jumbo Shrimp: The Rise and Fall of Large American Cities. Corporate Knights Magazine

Royal Academy of Engineering, 2012. Engineers for Africa: Identifying engineering capacity needs in Sub-Saharan Africa. A summary report and Supporting document 1: Literature review

UNESCO Report, 2010. Engineering Issues, Challenges and Opportunities for Development

© ASCE 2014

City of Los Angeles – the Green Blue City One Water Program, Part 1 of 5: Abstract, Introduction, Water Supply – Imported Water

Adel Hagekhalil, P.E., Shahram Kharaghani[1], P.E., Wing Tam[1], P.E., Richard Haimann[2], P.E.; Ken Susilo, P.E.[3]

[1]City of Los Angeles Bureau of Sanitation, [2]HDR, [3]Geosyntec

Abstract

The City of Los Angeles, with a population of over 4 million people, covering an area of over 400 square miles, is in a semi-arid region with a Mediterranean climate where local rainfall occurs over the course of a handful of storm events between October and May of each year. As such, the infrastructure has been developed to import water from Northern California and the Colorado River to provide water supply, and to route storm flows from the developed lands in the City to the Pacific Ocean rapidly and efficiently. This infrastructure has resulted in the development of one of the world's megacities as defined by the University of Southern California's Center on megacities.

While the City enjoys protection from flood risks and a dependable water supply of imported water, the receiving waters within the City suffer from impairments and numerous Total Maximum Daily Load (TMDL) regulations are being promulgated compelling the City to improve the quality of its stormwater runoff to lower the pollutant discharges from its urban streetscapes. Additionally, the imported water supplies that the City enjoys are expected to not be expandable and, with impending climate change modifying Sierra snowpack storage and state-wide meteorology, may decrease with time.

To meet both challenges, the City has put in place water management programs to reduce reliance on imported water supplies and to prevent the discharge of pollutants onto and from its streets and storm drain systems. The program is moving the City toward water sustainability and is being termed as the Green-Blue City of Los Angeles Water Management Program.

The program consists of several elements:

- A low impact development ordinance requiring most new and re-development to retain, infiltrate, evapotranspirate, and/or use on site the volume of water from the 85th percentile storm. This represents the most of the storm events that occur and the largest storm expected to occur in most years.
- An enhanced watershed management planning program where regional and distributed projects are being planned to capture and infiltrate, evapotranspirate,

© ASCE 2014

and/or use the volume of water from the 85th percentile storm from areas that do not have such systems on private parcels.

- A $500 million dollar voter approved bond funded program to build capital projects throughout the City to capture and use or treat urban runoff and stormwater. This bond fund is referred to as proposition O and was passed in 2004. Since passage of the measure, the funds have been allocated to projects and most of those projects have bee built. Most of the projects have multiple benefits derived from the use of green StormWater infrastructure. The projects include:
    - South Los Angeles Wetland Park Project
    - Cesar Chavez Recreational Complex
    - Hansen Dam Recreational Area Parking Lot And Wetlands Restoration
    - Echo Park Lake Rehabilitation Project
    - El Sereno Parking Grove
    - Cabrito Paseo Walkway & Bike Path
    - Los Angeles Zoo Parking Lot
    - Rory M. Shaw Memorial Wetlands Park (formally Strathern Wetlands)
    - Wilmington Drain Multi-Use Project
    - Machado Lake Ecosystem Rehabilitation Project
    - Rosecrans Recreation Center Stormwater Enhancements
- Development of standard plans and specifications for green streets features for new and re-development and for street right of way improvements.
- Development of a recycled water master plan with goals of more than doubling the amount of wastewater recycling with drinking water aquifer recharge as a significant element.
- Development of a stormwater capture master plan with goals of capturing local stormwater for recharging drinking water aquifers or direct use where feasible throughout the City.

1 Introduction

Los Angeles, California contains a population of over 4 million persons, making it the second largest city in the United States. When considering the metropolitan region, which consists of Los Angeles, Ventura, San Bernardino, Riverside, and Orange Counties, the region contains a population of over 18 million persons. The University of Southern California Viterbi School of Engineering “Megacities” program states: “Los Angeles is one of three "megacities" in the United States and 15 worldwide that will continue to grow at unprecedented rates well into the 21st century.” (http://viterbi.usc.edu/news/news/2008/megacities-a-new.htm)

© ASCE 2014

1.1 Economy

The region's 2012 gross domestic product was estimated to be over $765 Million (U.S Bureau of Labor Statistics), which makes the region approximately the 18th largest economy in the world. California with a 2012 gross domestic product of approximately $2 Billion (U.S. Bureau of Labor Statistics) would rank approximately 9th to 10th (http://en.wikipedia.org/wiki/List_of_countries_by_GDP_(nominal)).

1.2 Climate

Los Angeles enjoys a Mediterranean climate, which is characterized by year-round mild temperatures with seasonal rainfall concentrated in the winter months. Average annual rainfall for Los Angeles County is 15.65 inches (County of Los Angeles Department of Public Works Hydrologic Report, 2011-2012). At the Los Angeles Civic Center, the average annual rainfall between 1877 and 2012 was approximately 15 inches. This rainfall typically occurs between the months of October and May.

The region consists of the San Gabriel Mountains to the east and north with a coastal plain between the mountains and the Pacific Ocean. Most of the development has occurred on the coastal plain, which has been largely filled with urban/suburban type of development.

1.3 Flooding

Given the nature of the climate that concentrates the rainfall in the winter months, flooding has occurred historically with the local hydrographic landscape. The original rivers were generally intermittent and would meander broadly through the coastal plains when a significant storm system would produce large amounts of rain, damaging property and causing injury or taking lives. In response to these events, the Counties within the region formed flood control districts, which in turn created infrastructure to prevent river meander and expediently convey rain waters to the Pacific Ocean at rates that would lower flood risks to acceptable levels.

1.4 Drought

Drought has also been a persistent condition of the local climate. While rainfall is concentrated in the winter months, it has varied significantly year to year. Looking again at the rainfall measured at the Los Angeles Civic Center, while the average annual rainfall between 1877 and 2012 was approximately 15 inches, the minimum measured in one year was 3.21 inches in 2006-2007 and the maximum measured in one year was 38.18 inches in 1883-1884.

1.5 Water Supply

Given the fact that annual precipitation varied widely, to provide a dependable water supply that would support the growth of a large urban center in the Los Angeles Mediterranean climate, large scale water diversion projects were developed that

© ASCE 2014

delivered water to Los Angeles from more dependable water supplies in Northern California and the Colorado River. The first was the development of the Los Angeles Aqueduct, which diverted water from the Eastern Sierra snowmelt in the Owens Valley and transported the water to the City of Los Angeles. This project was completed in 1913 by the City of Los Angeles. In the 1930s, the Metropolitan Water District of Southern California (MWD) completed the Colorado River Aqueduct, which diverted Colorado River water to the Los Angeles area. In the 1960s, the California State Water Project diverted water from rivers in the Central Valley to the California Aqueduct, which delivers the water to the Los Angeles Area.

Figure 1-1 shows the average water supply mix for the Los Angeles region between 1976 and 2010 (The Regional Urban Water Management Plan, The Metropolitan Water District of Southern California, November 2010).

1.6 Water Quality

Given the widespread development of the region and the flood risk mitigation infrastructure that conveys runoff quickly to the Ocean, the quality of most of the receiving waters within the Los Angeles region are listed on USEPA's 303(d) list of impaired waters (http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml).

In 1999 a consent decree was lodged in Federal Court (Heal the Bay Inc., et al v. Browner, et al, C 98-4825 SBA), requiring EPA to approve or develop TMDLs for water bodies and pollutants throughout Los Angeles County. The consent decree was amended in 2010 to reflect changes in the 303(d) list and as of 2013, 57 TMDL actions have been taken for over 175 water bodies that address numerous pollutant impairments including elevated bacteria, metals, pesticides, PCBs and trash. There are 257 (pollutant/receiving water combination) impairments with 226 under a TMDL.

In November, 2012, a new National Pollutant Discharger Elimination System (NPDES) permit was adopted by the Regional Water Quality Control Board (RWQCB) for regulation if discharges from the City's Municipal Separate Storm Sewer System (MS4). The City is one co-permittee along with Los Angeles County and 83 other cities within Los Angeles County. The RWQCB is the state agency responsible for Clean Water Act (CWA) implementation and enforcement.

© ASCE 2014

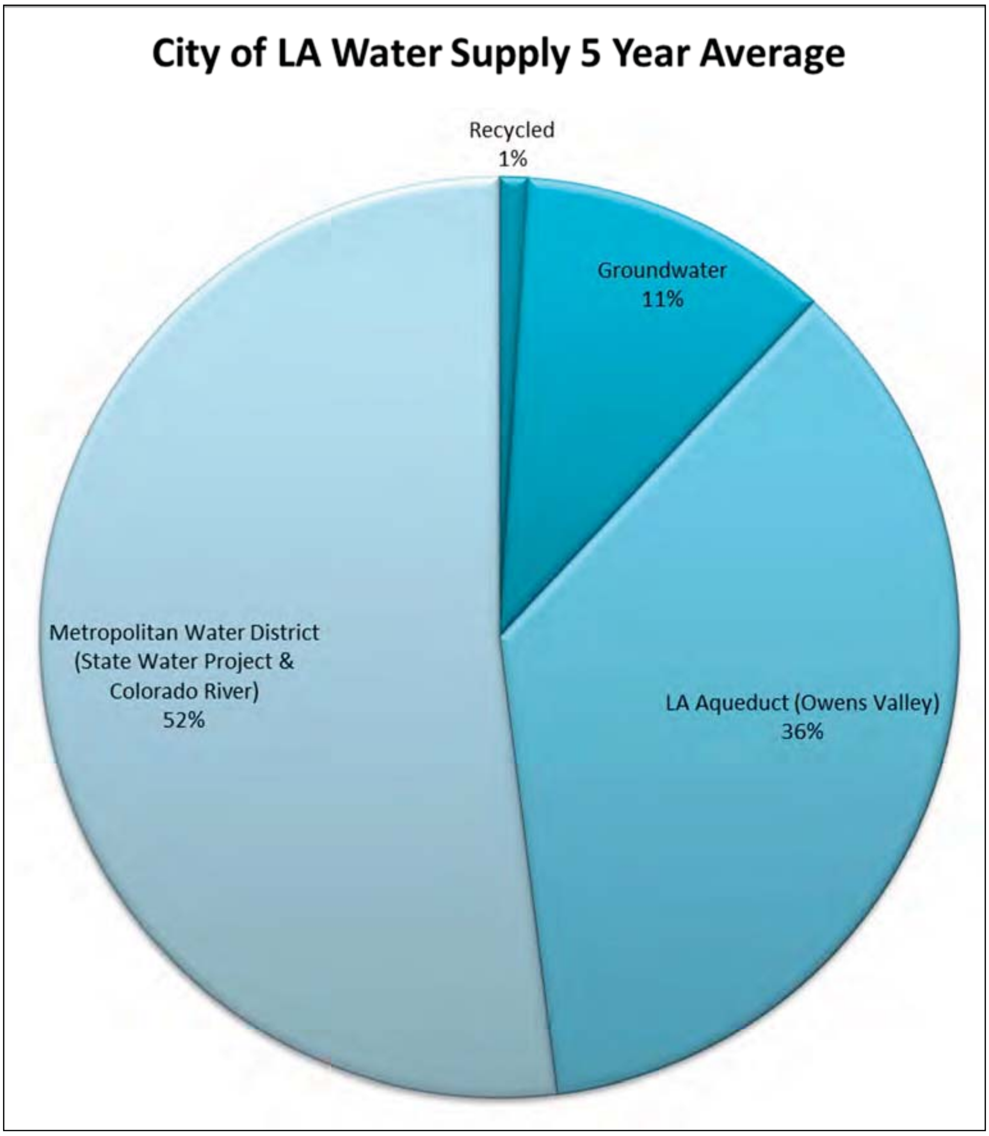


Figure 1-1: 5 Year Average Los Angeles City Water Supply Mix (https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-water/a-w-factandfigures)

Within this MS4 permit, the adopted TMDLs were incorporated as permit conditions under a Watershed Management Planning approach. Each permittee is required to submit a Watershed Management Plan (WMP) that outlines the steps they will take during and after the term of the permit (5 years) to achieve Waste Load Allocations (WLAs) specified in the TMDLs. The permit also allows permittees to prepare cooperative plans, called Enhanced Watershed Management Plans (EWMPs), which are for a watershed and define the steps the participating agencies will take to collaboratively achieve the WLAs specified in the TMDLs within that watershed.

Given the concurrent conditions the city is facing of a limited water supply and increasingly more stringent requirements for runoff and discharges from the City into the receiving water, the City has developed a "One Water" approach to planning to

© ASCE 2014

meet multiple water needs. The City has coined the term "Green-Blue" Los Angeles to describe this approach.

One Water Approach

Under this one water approach, the City of Los Angeles Bureau of Sanitation and the Department of Water and Power have collectively been planning their respective parts of an overall vision to increase local waters supply and reduce pollutant loads from the City's urban landscape. Figure 1-2 shows a graphic of the City's one water vision.

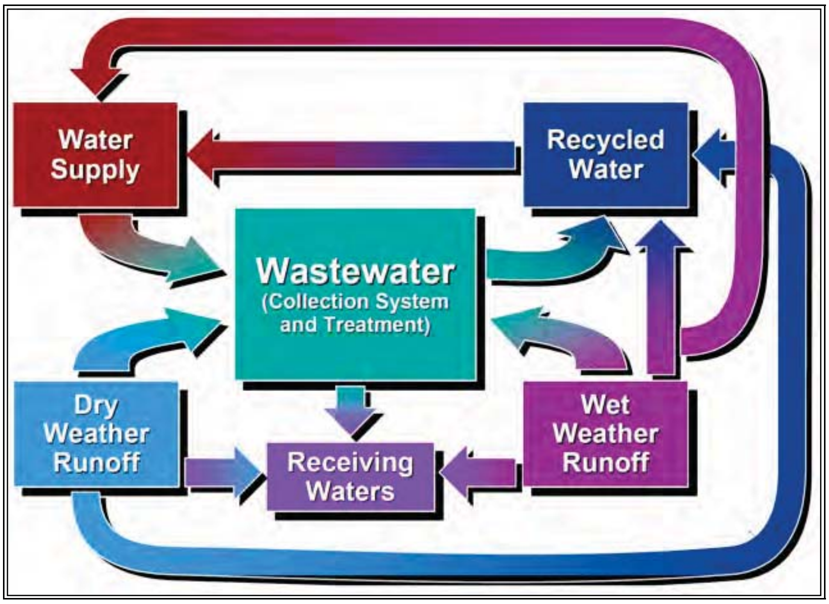


Figure 1-2: City of LA's One Water Vision (2006 City of Los Angeles Recycled Water Master Plan)

The City sees all the water it manages as one water, whether that is a potable supply, a wastewater, or stormwater runoff. They city has been investing in assets to manage this water as one water to derive the highest possible value from it.

2 Water Supply

As noted above, Los Angeles derives over 60% of its water supply from imported sources. New water is likely not available for diversion from other parts of California or the U.S. In fact, diversions from the Owens Valley to Los Angeles have been declining for environmental mitigation purposes. Figure 2-1 shows water supplies to Los Angeles from 1980-2010. This plot shows Los Angeles Aqueduct (Owens Valley) deliveries declining with the difference made up by MWD water with some growth in recycled water supply that is used for irrigation and injection barrier management.

© ASCE 2014

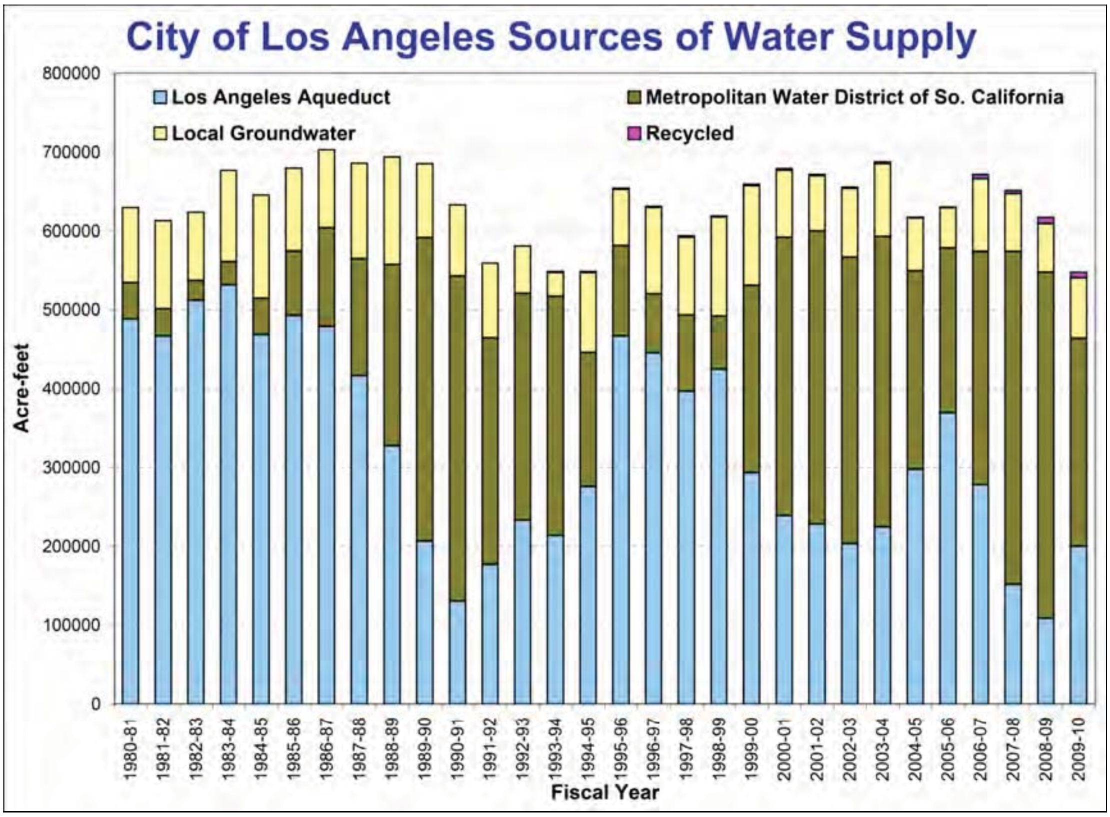


Figure 2-1: City of Los Angeles Water Supply: LADWP 2010 Urban Water Management Plan

However, MWD is facing restrictions on securing additional water supplies. This is evident in changes in pricing strategies MWD has employed to fund increased reliability of existing water supplies and increase system storage to provide greater amounts of water during dry years. Figure 2-2 shows price increases for Tier 1 water, which is the water that MWD estimates it can provide every year without fail. Additional water beyond the Tier 1 water is billed at Tier 2 rates. Figure 2-3 shows changes in Tier II rates. Tier II rates were first implemented in 2003. Assuming that water purchasers, such as the City of LA used 2/3 tier I water and 1/3 tier II water, their MWD rates for untreated water would have trended as shown in Figure 2-4. The potential percent increase in MWD water rates for a purchaser using 2/3 tier I water and 1/3 tier II water since 2002 is shown in Figure 2-5.

© ASCE 2014

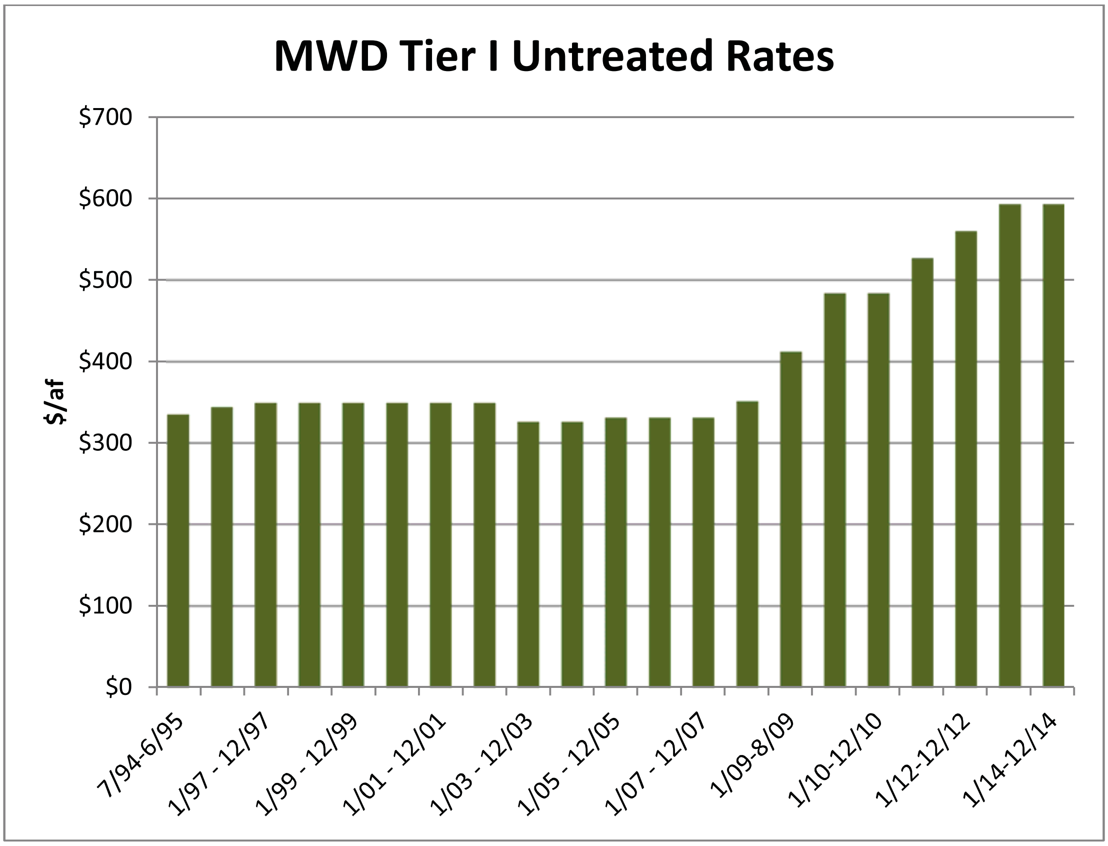


Figure 2-2: MWD Untreated Tier I Water Rates

Thus, water rates for imported water have almost doubled in 11 years. It is still uncertain if these rates are sufficient to secure additional water supply from Northern California or the Colorado River Basin, as these supplies are allocated at this time. Further diversions to Los Angeles would likely require reductions in use somewhere else in the basins from which that water is derived, which is generally believed to be agriculture.

© ASCE 2014

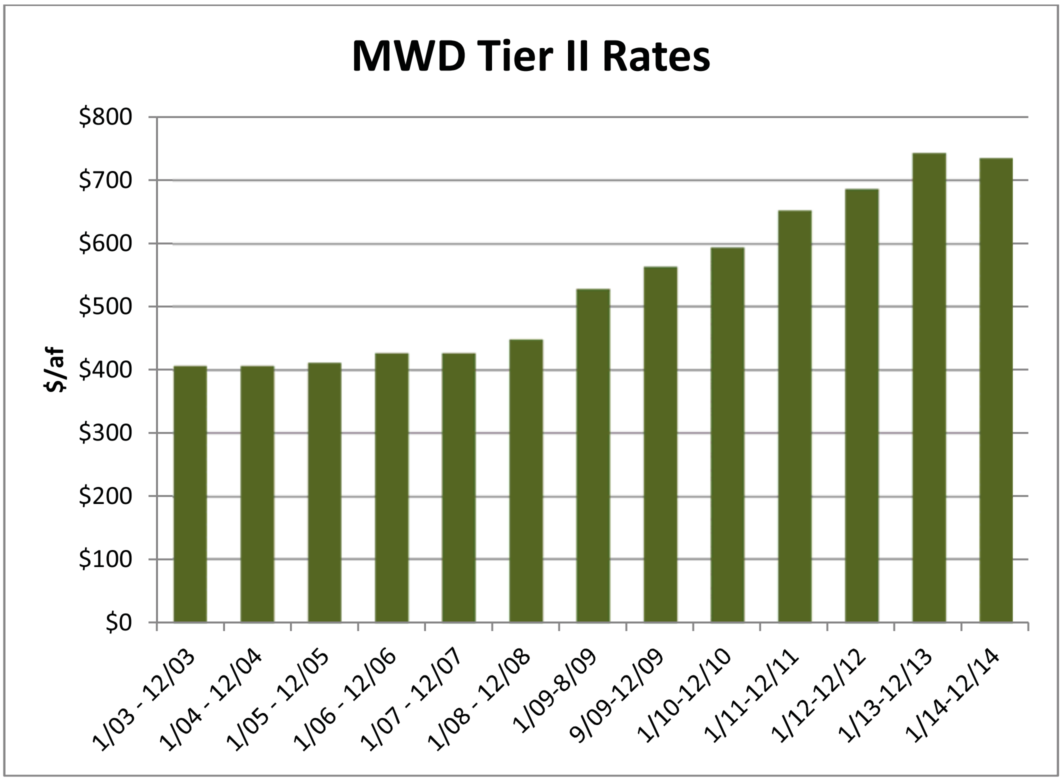


Figure 2-3: MWD Untreated Tier II Water Rates

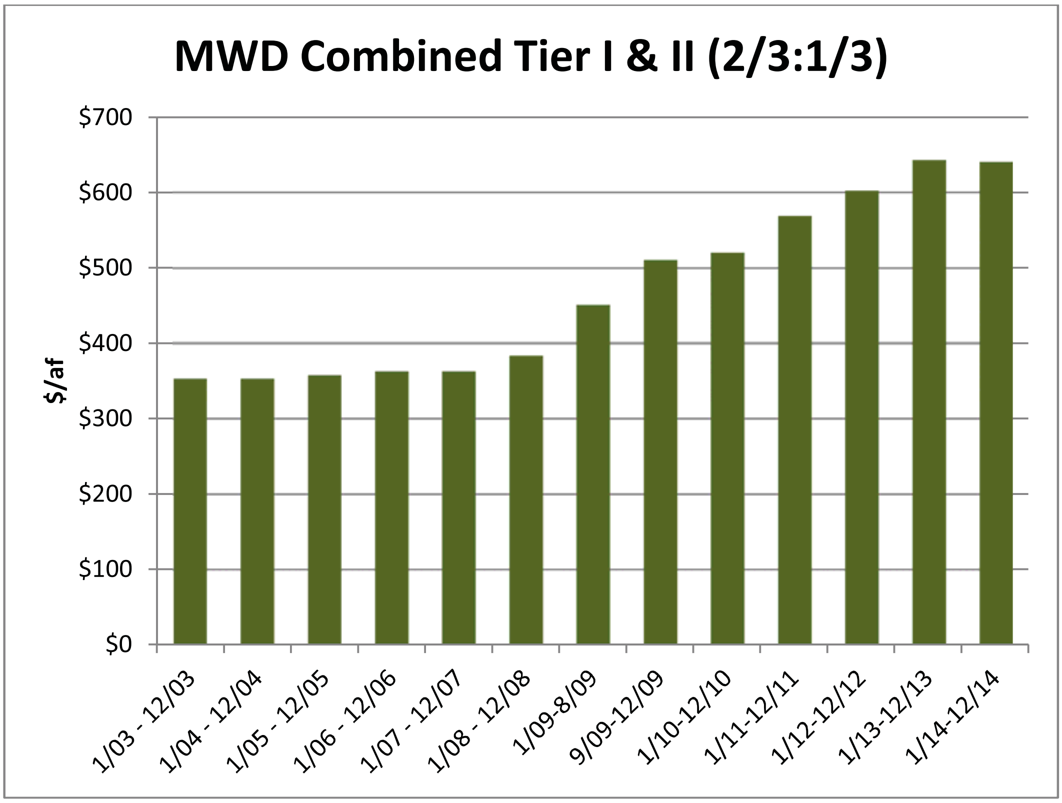


Figure 2-4: Combined Tier I and Tier II rates assuming 2/3 Tier I and 1/2 Tier II purchases.

© ASCE 2014

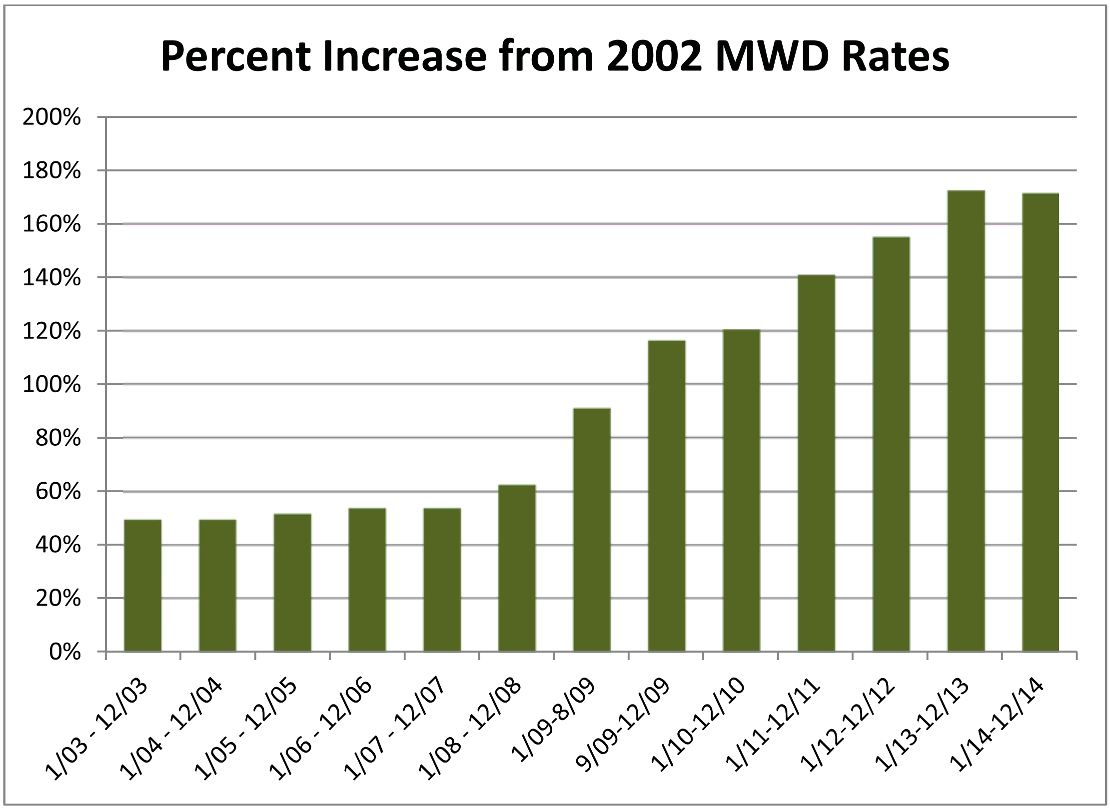


Figure 2-5: Percent Increase over 2002 Water Rates (Before Tier II) assuming 2/3 Tier I and 1/3 Tier II

The City and County of Los Angeles have built infrastructure to capture locally derived rainwater for water supply purposes. The Los Angeles County Department of Public Works operates spreading basins under agreement with the US Army Corps of Engineers to recharge groundwater with stormwater captured within dams upstream of those spreading grounds. The City of Los Angeles, similarly, also operates some spreading grounds. Together the City and County capture and recharge on average 27,000 acre-feet per year of local stormwater. Figure 2-6 shows the historical amount of rainfall captured and recharged in the Los Angeles area.

© ASCE 2014

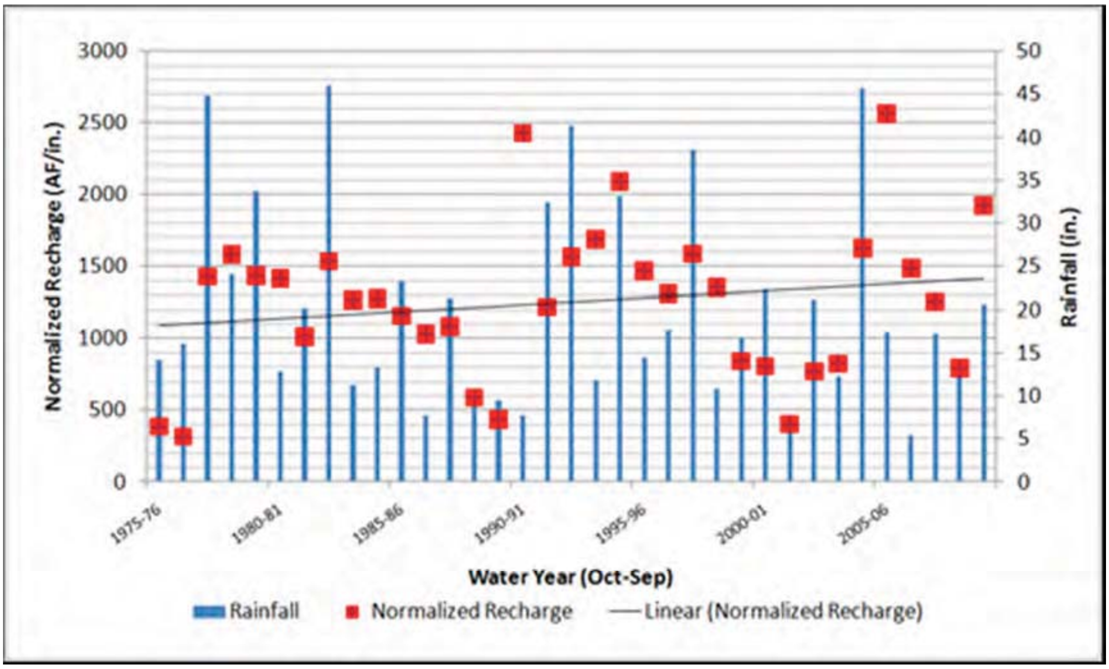


Figure 2-6: Historical Stormwater Recharge in Los Angeles (Hanna, M., T. Erb, W. Tam, P. Reidy, and B. Steets, 2011. Increasing the Cost Effectiveness of Stormwater and Rainwater Harvesting for Water Supply and Water Quality in Los Angeles. StormCon 2011)

In response to increased costs of imported water supplies and concern regarding availability of additional imported water supplies, the City of Los Angeles through LADWP and Bureau of Sanitation (BOS) have been developing integrated resource plans for broadening local water supplies. These plans include the following elements:

- Recycled Water
  - Broadening non-potable customer base
  - Indirect potable reuse through groundwater recharge
- Groundwater
  - Restore the San Fernando Basin
  - Expand Groundwater Storage
- Conservation Expansion
- Stormwater Capture (Stormwater Capture Master Plan)

© ASCE 2014

City of Los Angeles – the Green Blue City One Water Program, Part 2 of 5: Water Supply, Continued - Recycled Water, Conservation, Storm Water Harvesting

Adel Hagekhalil, P.E., Shahram Kharaghani[1], P.E., Wing Tam[1], P.E., Richard Haimann[2], P.E.; Ken Susilo, P.E.[3]

[1]City of Los Angeles Bureau of Sanitation, [2]HDR, [3]Geosyntec

1 Water Supply, Continued

1.1 Recycled Water

The City has been recycling wastewater since 1979 when it began providing tertiary treated wastewater for non-potable use in the Griffith Park Area. Prior to that time, in the 1960s, the City elected to invest in wastewater treatment upstream within their collection system network so that they could divert those wastewater flows to customers, rather than expanding their terminus treatment capacity. Since then, the City has expanded its recycled water program and currently produces and distributes approximately 19,350 acre-feet per year (afy). This water is used primarily for irrigation and serves City public parcels as well as some private customers.

The City has developed a plan to expand recycled water production and use to 59,000 afy. Figure 1-1 shows the City's existing and planned recycled water system. Because of decisions the City made decades ago to acquire land and construct treatment works in the San Fernando Valley (Donald C Tillman Water Reclamation Plant [DCTWRP]) and near Glendale-Burbank (Los Angeles Glendale Water Reclamation Plant [LAGWRP]), the City is poised to expand their recycled water system to reduce wastewater flows and reduce potable water demand.

The City's expansion plans are for two programs:

- Groundwater Replenishment
- Non Potable Reuse

1.1.1 Groundwater Replenishment

The City is planning to add advanced treatment to the DCTWRP to capture 30,000 afy per year of wastewater, treat it with microfiltration, reversed osmosis, and advanced oxidation, and infiltrate the water into the San Fernando Basin at the Tujunga, Hansen, and Pacoima Spreading Grounds, as well as the Rory M. Shaw Memorial Wetlands Park (formerly Strathern Wetlands). Figure 1-2 shows the groundwater replenishment system layout.

© ASCE 2014

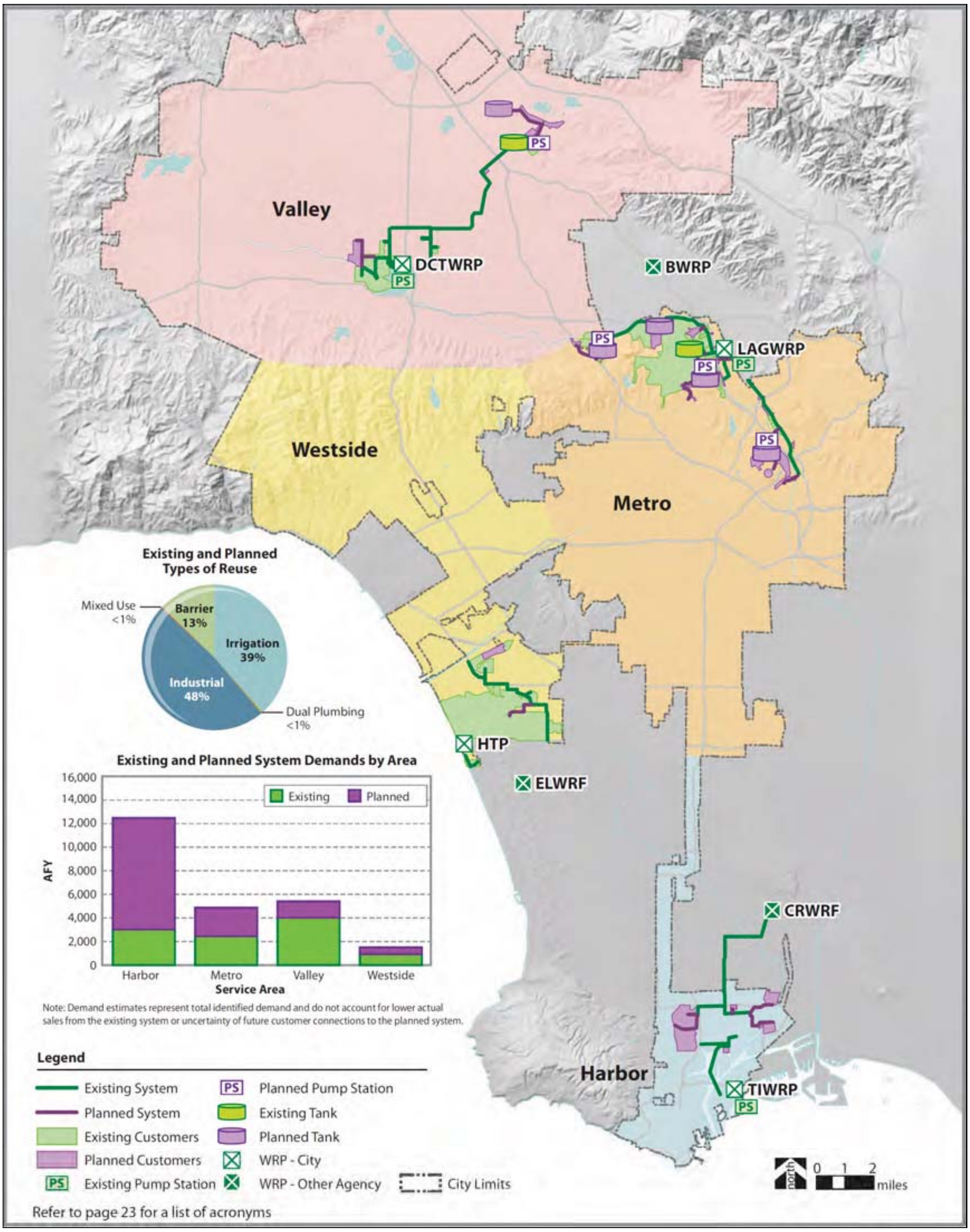


Figure 1-1: Existing and Planned Recycled Water Infrastructure (City of LA 2012 Recycled Water Master Plan)

The San Fernando Basin is currently one of the largest groundwater supply basins for the City of Los Angeles and this project will augment that supply significantly. This will be done in conjunction with a groundwater restoration project the City is undertaking that is discussed later in this paper.

© ASCE 2014

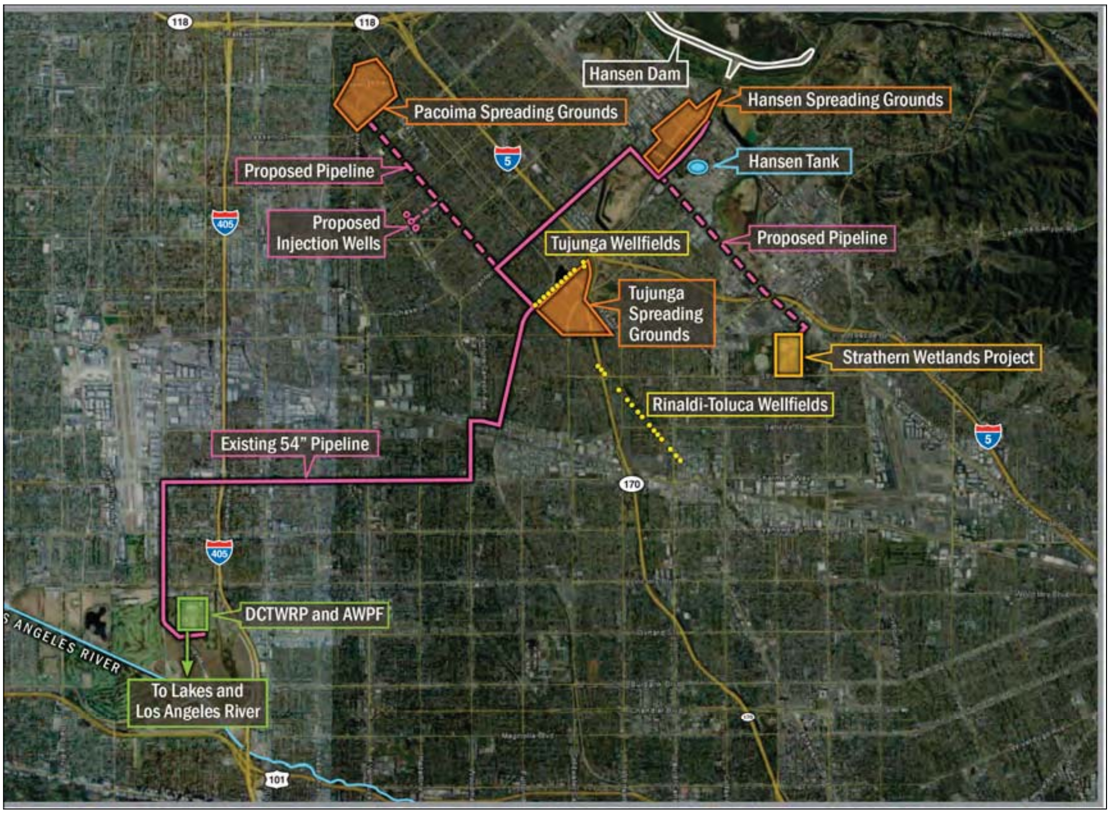


Figure 1-2: Groundwater Replenishment system Layout (City of LA 2012 Recycled Water Master Plan)

1.1.2 Non-Potable Reuse

The City is actively seeking additional anchor customers who would purchase more than 50 afy. Once such an anchor customer is secured, the City can then finance the construction of conveyance to the anchor customer's premises. Such customers would use recycled water for such purposes as:

- Landscape irrigation
- Industrial process water
- Cooling water
- Habitat Restoration

Once conveyance is constructed to an anchor customer, additional customers would generally begin to purchase smaller quantities of recycled water for such uses as:

- Toilet flushing
- Car washing
- Dust control during construction
- Commercial cleaning

© ASCE 2014

With the implementation of EPA's 316(b) regulations and California's State Implementation Policy for 316(b), which restricts the use of single pass cooling systems, many power generation facilities, including those owned and operated by LADWP, are being modified to use closed loop cooling systems. Closed loop cooling systems need make-up water to replenish the evaporative losses from the systems. These represent potential future anchor customers, particularly in the vicinity of the Terminal Island Treatment Plant at the Port complex.

Figure 1-3 shows existing, planned, and potential future customers for non potable reuse of recycled water. These customers are expected to purchase up to more than 9,650 afy. Since connecting to the recycled water system is voluntary, and requires permitting from the RWQCB and, possibly, California Department of Public Health (DPH), there is uncertainty over how much more than 9,650 afy will be purchased. Considering how many industrial, irrigation, habitat, and other water purchasers exist and are connected to the City's potable water system, it is quite possible that 29,000 afy of non potable reuse customers can be connected to the City's recycled water systems.

1.2 Groundwater

The City of Los Angeles has water rights in the San Fernando Basin Groundwater Basin, the Central Basin Groundwater Basin, and the West Coast Basin Groundwater Basin, and the Sylmar Basin. The City is in proximity to the Hollywood Basin, Santa Monica Basin, Verdugo Basin, and Eagle Rock Basin. Figure 1-4 shows the groundwater basins of Los Angeles.

The San Fernando Basin Groundwater Basin (SFB) has been the City's primary source of groundwater and is the basin to which the City has its greatest allowable pumping allocation. The SFB accounts for more than 80% of the city's total local water rights. Unfortunately, portions of the SFB have been contaminated from historical industrial activity with chlorinated solvents, hexavalent chromium, 1,4-dioxane, N-Nitrosodimethylamine (NDMA), and nitrates. The USEPA has listed the SFB on the National Priorities List for Superfund Cleanup and has been investigating, directing interim actions, and developing a set of remedies since the mid-1980s.

Because of reduced imported water supplies and increased costs of imported water, LADWP is moving forward to build treatment systems to treat contaminated groundwater from the SFB to potable standards. This treatment system will provide approximately 123,000 afy of potable water supply from the SFB that is currently recharged with regional stormwater capture and infiltration projects and imported water and will, in the future, be recharged with recycled water.

© ASCE 2014

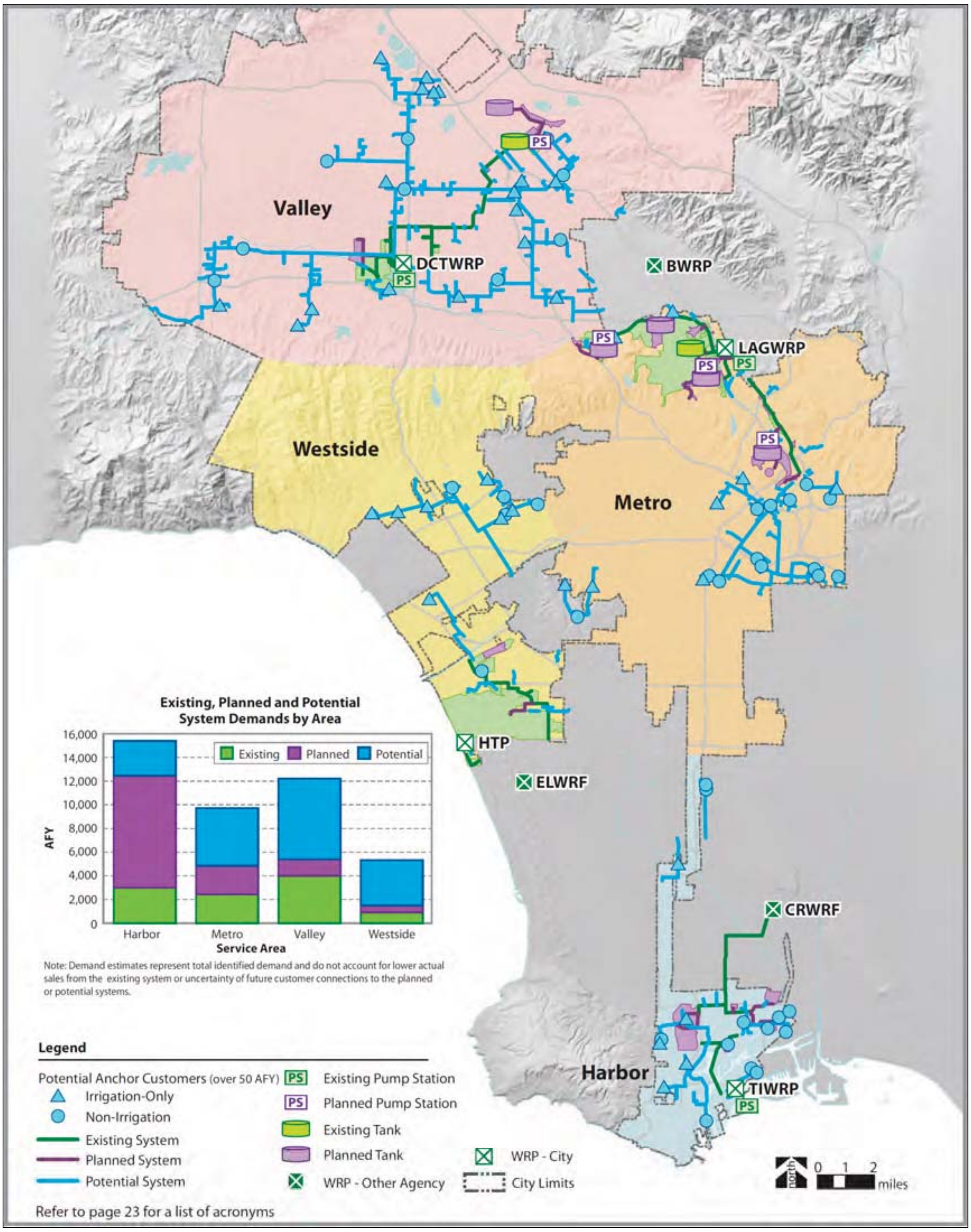


Figure 1-3: Existing, Planned, and Potential Non Potable Reuse Customers (City of LA 2012 Recycled Water Master Plan)

© ASCE 2014

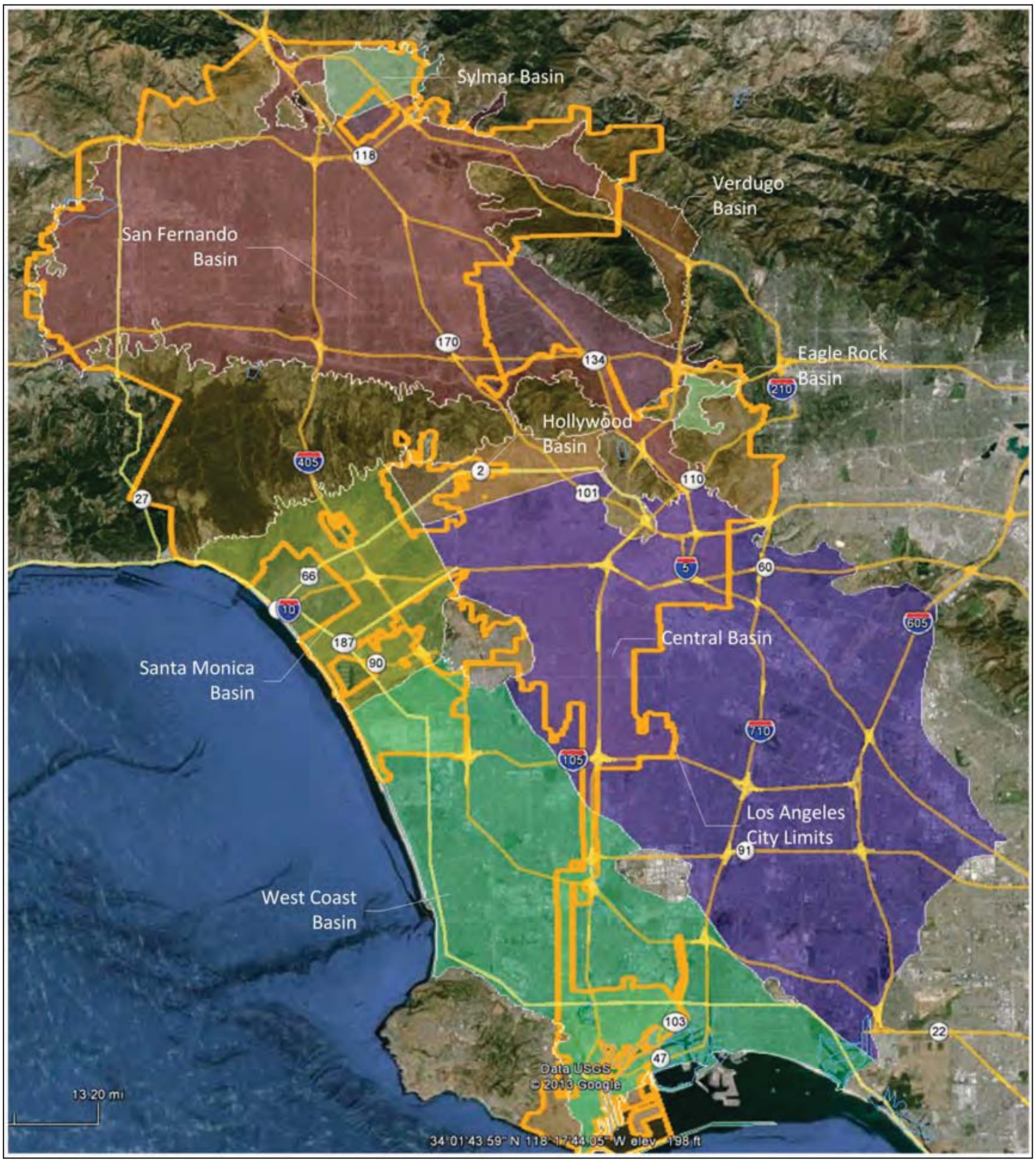


Figure 1-4: Groundwater Basins of Los Angeles

1.3 Conservation

The City of Los Angeles has a water conservation program in place that has resulted in measureable reductions in per capita water consumption. Figure 1-5 shows the historical water demand and population for the City.

© ASCE 2014

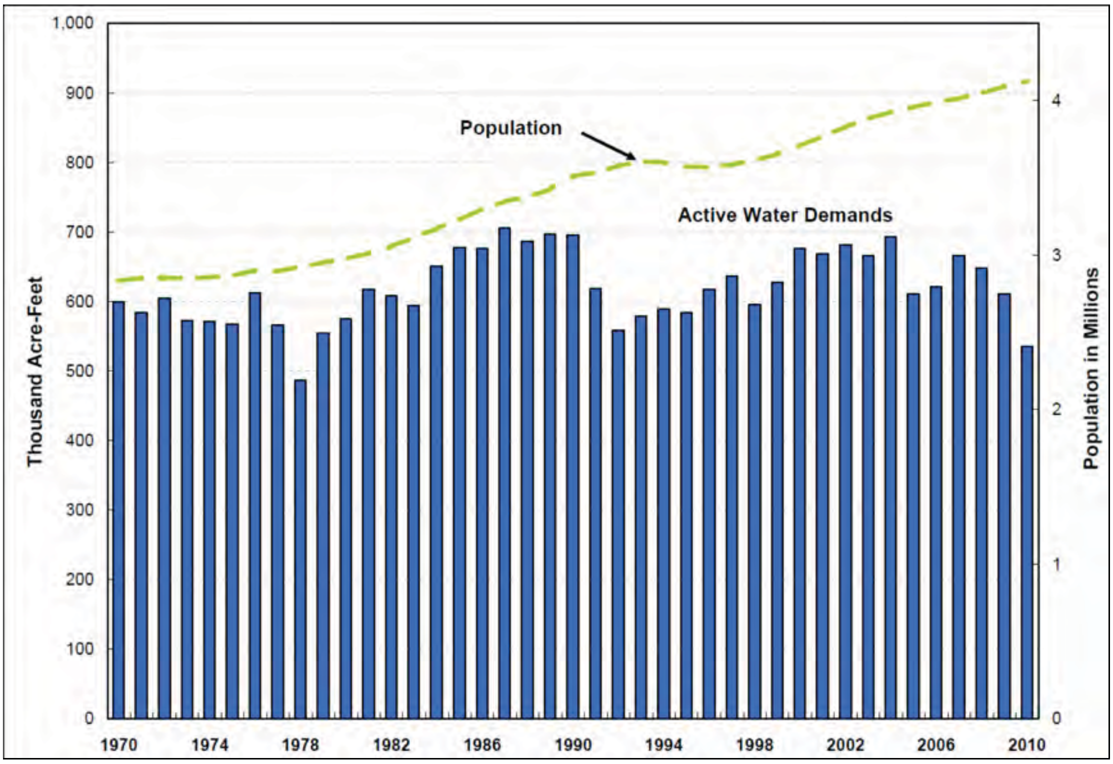


Figure 1-5: Historical Water Demands and Population for City of Los Angeles (LADWP 2010 Urban Water Management Plan)

As can be seen in Figure 1-5, total water demand has remained steady or decreased while population has increased showing that per capita water demand has decreased through water conservation programs and customer changes.

To continue these trends, LADWP is implementing the following programs:

- Residential Smart Sprinkler Systems. Install 5,250 weather-based smart sprinkler controllers per year, with a total of 63,500 by 2020. LADWP expects to achieve water savings of 4,962 AFY by 2030.
- Conservation Rebates and Incentives. LADWP is providing financial incentives to increase participation in the water conservation rebate and incentive programs. This includes rebates for high efficiency washers and other appliances. LADWP expects to achieve water savings of 48,457 AFY by 2030.
- Targeting City Parks and Large Landscapes with weather based smart sprinkler controllers. LADWP intends to retrofit 3 parks per year.
- Targeting public buildings. LADWP intends to retrofit water fixtures in City owned public buildings with high efficiency fixtures.
- Public Education and Outreach. LADWP budgets $2M to $3M per year for water conservation outreach to persuade customers to be “drought busters” and conserve water.

© ASCE 2014

1.4 Stormwater Capture.

LADWP, in conjunction with the Los Angeles County Department of Public Works and Flood Control District (LACDPW) operate large scale regional stormwater capture and infiltration projects. Table 1-1 shows the facilities that recharge the SFB, which LADWP can then extract from its well-fields.

Table 1-1: LADWP/LACDPW Spreading Grounds

Spreading Basins	Area (acres)	Recharge Capacity (cfs)	Recharge Capacity (AFY)	Source Water	Owner
Hansen	105	49	35,000	Runoff	LACDPW
Pacoima	107	40	23,000	Runoff	LACDPW
Lopez	12	7	2,000	Runoff	LACDPW
Branford	7	1	1,000	Runoff	LACDPW
Tujunga	83	99	43,000	Runoff	LADWP
Total	314	196	104,000	--	--

In addition to this, LADWP is planning to expand its stormwater capture program substantially through both enhancing its existing infiltration facilities and constructing new regional and distributed stormwater harvesting systems. LADWP is currently preparing a Stormwater Capture Master Plan (SCMP) to identify specific projects that will cost-effectively increase local water supplies through adding additional local stormwater either to the groundwater supplies, capturing stormwater for direct use, or by offsetting potable water use through the use of local capture systems such as rain barrels. Figure 1-6 shows the goals of the stormwater capture program.

L.A's Water Reliability 2025 Program	Water Generated (AFY)
Centralized Capture	54,800
Distributed Harvesting (Decentralized)	7,600
Total	62,400
2010 Urban Water Management Plan	
Centralized Capture	15,000
Distributed Harvesting (Decentralized)	10,000
Total	25,000

Figure 1-6: Stormwater Capture Goals 2025 (Presentation by David Pettijohn, LADWP, to California State Senate, May 10, 2013)

Projects currently identified and/or recently built include:

© ASCE 2014

- Woodman Avenue Multi-Benefit Stormwater Capture and Infiltration Project
  - 65 AF of annual recharge.
  - Collects water from 130 acres of a "Disadvantaged Community" in the San Fernando Basin.
  - Vegetated swales and underground infiltration galleries to replace 16 ft by 3,500 ft concrete median.
  - Construction to be completed in August 2013.
  - Total estimated cost is $3.4M of which LADWP will fund $1.0M.
  - Collaborative effort with the City of Los Angeles Bureau of Sanitation (LABOS), Bureau of Street Services (LABSS), and The River Project
- Tujunga Spreading Grounds Enhancement Project
  - Involves deepening and consolidation of multiple basins
  - Doubles recharge volume from 8,000 to 16,000 AF per year
  - 150 acres of spreading grounds
  - Installation of two 60-foot inflatable dams to divert water from Tujunga and Pacoima Washes
  - Currently 90% design, Construction complete in 2016
  - Construction Cost – $20M
- Pacoima dam sediment removal project
  - Adds nearly 3,000 AF of capacity through removal of 2.4-5.2 million cubic yards of accumulated sediment.
  - Annual average recharge at downstream spreading grounds is 27,000 AFY – water that would otherwise be wasted to the Ocean.
  - Construction anticipated for 2014.
  - 5-year project duration.
  - LADWP's contribution $10M of $85M total cost.
  - LADWP partnering with Los Angeles County Flood Control District.

© ASCE 2014

City of Los Angeles – the Green Blue City One Water Program, Part 3 of 5: Pollutant Load Reduction – Public Green Infrastructure

Adel Hagekhalil, P.E., Shahram Kharaghani[1], P.E., Wing Tam[1], P.E., Richard Haimann[2], P.E.; Ken Susilo, P.E.[3]

[1]City of Los Angeles Bureau of Sanitation, [2]HDR, [3]Geosyntec

1 Pollutant Load Reduction

The City of Los Angeles Bureau of Sanitation Watershed Protection Division is the division responsible for compliance with the MS4 NPDES permit, which now includes a requirement that the City submit a watershed management plan to show the steps the City will take to cut runoff pollutants to meet waste load allocations and water quality objectives.

The City of Los Angeles has elected to prepare enhanced watershed management plans (EWMPs) in conjunction with Los Angeles County and the cities within the four watersheds the City of Los Angeles has responsibilities within. These watersheds are the Upper Los Angles River watershed, the Ballona Creek Watershed, the Santa Monica Bay watershed (management areas 2 and 3) and the Dominguez Channel watershed. Figure 1-1 shows the City of Los Angeles watersheds. The blue lines represent streams that have TMDLs adopted for them and/or are listed as impaired on the 303(d) list.

The EWMPs will be completed in June, 2015. The City's vision in these plans is to use green infrastructure as much as practicable in order to achieve a water supply benefit, recreational benefits, environmental benefits, and aesthetic benefits from that infrastructure. The permit allows the permittees to capture and infiltrate or use beneficially the 85th percentile storm with monitoring as a method of compliance rather than strict adherence to a waste load allocation.

1.1 Public Green Infrastructure through Proposition O

The City has already been implementing green infrastructure projects that they were able to fund under a bond program called Proposition O. In California, special bond measures, new taxes, and new fees for public spending require public votes. Proposition O went to the ballots in 2004 and the voters of Los Angeles approved a $500M bond measure to fund water quality improvement projects throughout the City. A citizens' advisory oversight committee was formed from stakeholders within the community who screened and approved projects. The City established a proposition O division within is Bureau of Engineering to design and construct the projects that were approved for bond funding. To date, most of the projects have been constructed.

© ASCE 2014

These proposition O projects represent examples of the types of projects being envisioned in the City's EWMPs. The projects are multi-benefit, multi-agency, projects that had substantial stakeholder involvement in their development.

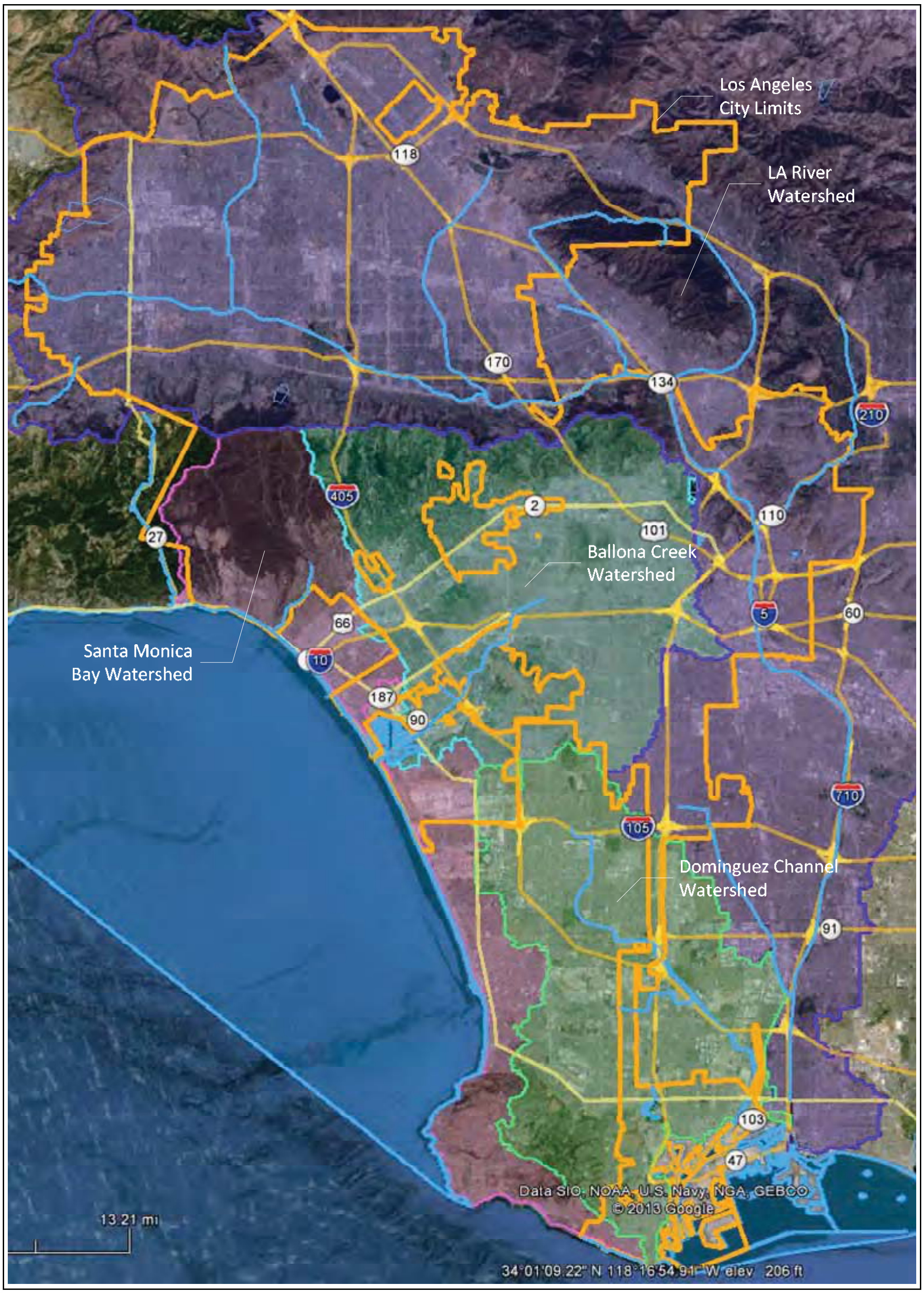


Figure 1-1: City of Los Angeles Watersheds

They generally provide water quality improvement, habitat improvement, recreation improvement, flood risk reduction, and/or water supply improvements.

© ASCE 2014

Other projects have been developed that are not funded from proposition O as well. Figure 1-2 shows the City of Los Angeles green infrastructure projects planned or built to date.

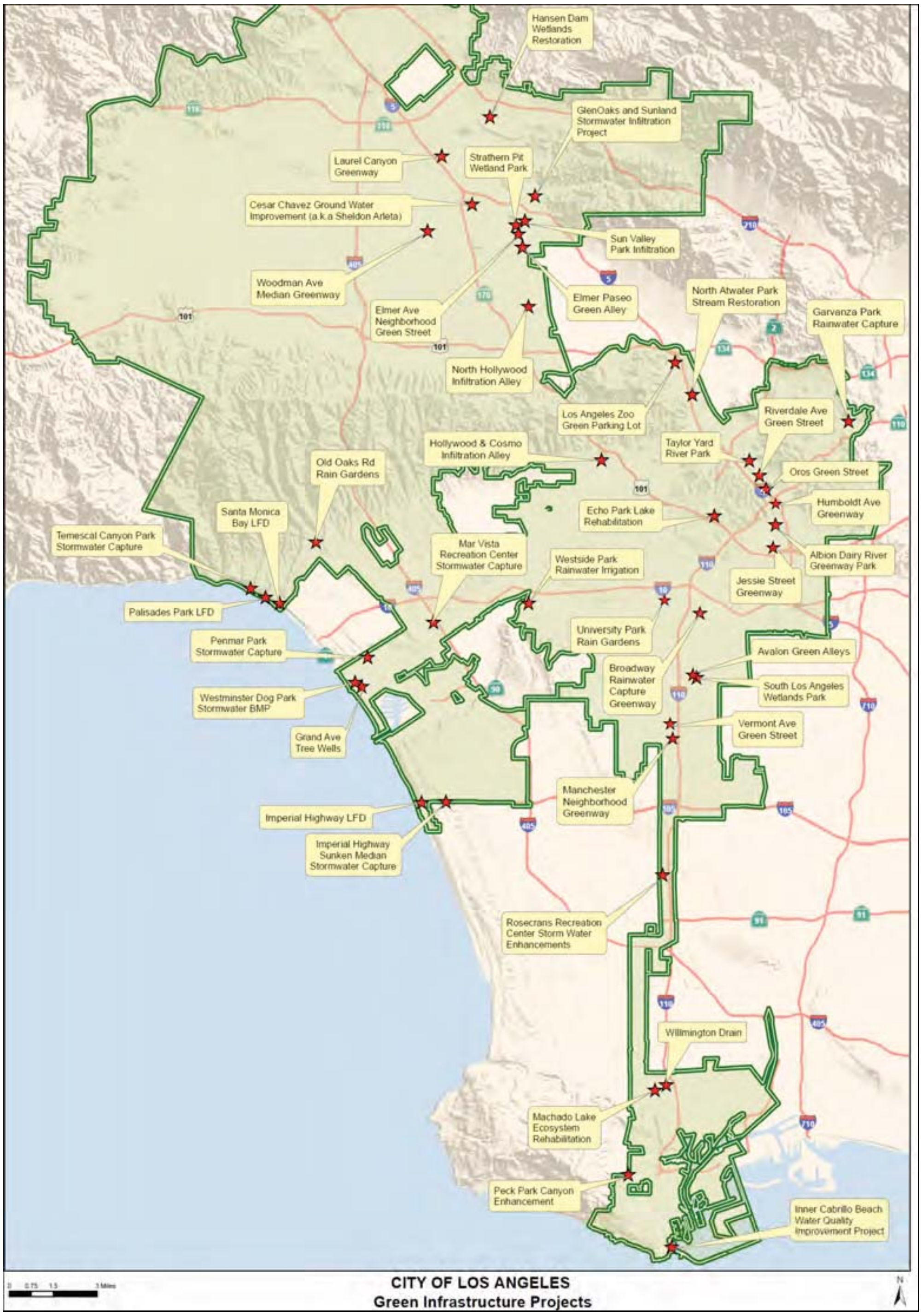


Figure 1-2: City of Los Angeles Green Infrastructure Projects

Because the EWMPs are under way, the projects the City will develop in those plans are not yet shown in Figure 1-2

© ASCE 2014

Below are the proposition O and related green infrastructure projects that provide a water quality and water supply benefit. Many provide other benefits such as habitat restoration, recreation, aesthetics, urban heat island reduction, and potentially community revitalization benefits as well.

- South Los Angeles Wetland Park Project
  - Stormwater pre-treatment best management practices (BMP) measures,
  - A stormwater treatment wetland of approximately 4.0 to 4.5 acres,
  - Renovation of an 81,760 square foot on-site structure,
  - Open park space, and
  - Parking lot with a vegetated swale to direct runoff into the wetland.
  - Wetland Park will provide educational opportunities and wildlife viewing, historical railway elements, a community multi-use center, and historical building reutilization.
  - Cost approximately $26 million.

Figure 1-3: South Los Angeles Wetlands Park

- Cesar Chavez Recreational Complex
  - Restore the water spreading capacity in the adjacent Tujunga Spreading Grounds (TSG) through renovation of the existing landfill gas collection system for the landfill.
  - Additional storm water recharge of approximately 10,800 acre-feet per year.
  - Phase II consists of extensive grading and earthwork to provide additional cover as well as establishing proper drainage patterns for the existing site.

© ASCE 2014

- Phase III involves park development for the site.
- The final development concept includes the following:
  - soccer fields;
  - baseball fields;
  - basketball courts;
  - children's play area;
  - splash pad;
  - jogging path;
  - bike path;
  - group and individual picnic areas;
  - service facility;
  - concession space;
  - restroom;
  - off-street parking;
  - security fencing and lighting; and
  - landscaped buffer areas.
- Cost approximately $9.5 million.

Figure 1-4: Cesar E. Chavez Recreational Complex Conceptual Plan

- Hansen Dam Recreational Area Parking Lot and Wetlands Restoration
  - Installation of bioswales and treatment wetlands to capture, treat and reuse wet and dry weather flows from three parking lots.

© ASCE 2014

- Redesign and resurface portions of one parking lot and redirect flows from this and two other parking lots into a complex of constructed stormwater treatment wetlands.
- Assist in improving stormwater quality within the LA River watershed, help meet the discharge limits of adopted TMDL's and remediate water quality impacts to sensitive habitats and special status/endangered species.
- Cost of approximately $2.2 million

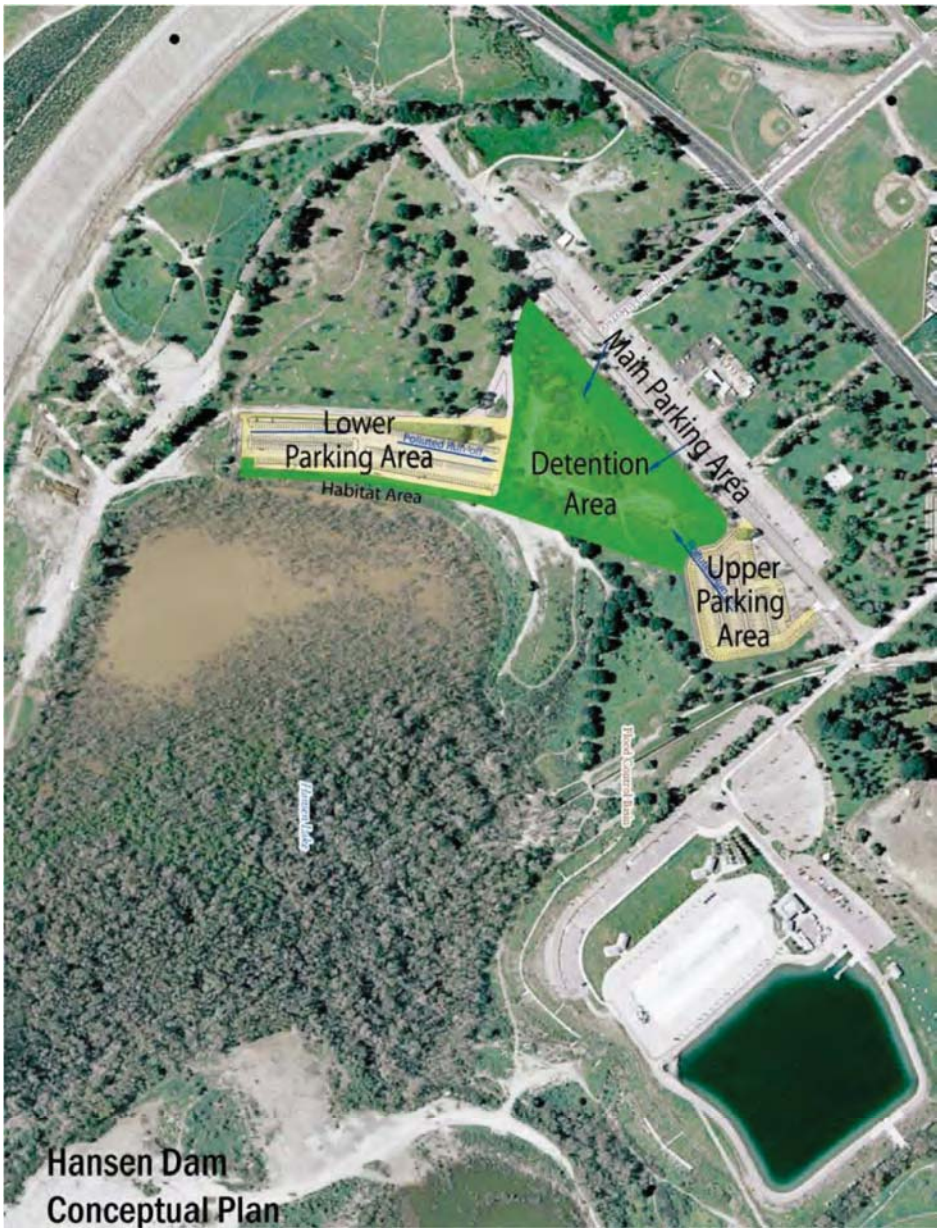


Figure 1-5: Hansen Dam Recreational Complex and Wetlands Conceptual Plan

- Echo Park Lake Rehabilitation Project
  - Draining the Lake and Removal of Contaminated Lake Sediments, Replacement of Lake Liner

© ASCE 2014

- Redesign of Concrete Storm Drain Inlet Structures
- Sediment Basin/Media Filter
- Lake Outlet Structure
- Potable Water Inlet
- Lake Aeration
- Grassy Swales/Infiltration Strips
- Porous pavement
- New "SMART" Irrigation System
- Educational Signage and Kiosks
- Costs of approximately $45 million


Figure 1-6: Echo Park Lake after restoration

- El Sereno Parking Grove
  - Stormwater enhancements include the installation of porous pavers, in a location that is currently used as a dirt parking lot, to encourage infiltration of runoff while reducing sediment loading to the storm drain system.
  - The parking lot is designed to incorporate rows of trees between parking stalls, which will allow for stormwater uptake and biofiltration, in addition to creating shade and enhancing habitat with native vegetation.
  - Additionally, a restroom facility would be installed in the parking lot area to replace the current portable toilets that are commonly overturned resulting in bacterial loading.
  - Costs of approximately $4 million.

Figure 1-7: El Sereno Parking Grove Preliminary Conceptual Design

© ASCE 2014

- Cabrito Paseo Walkway & Bike Path
    - Stormwater enhancements include a "smart" irrigation system,
    - Bioswales,
    - Trees wells and landscaping,
    - A graded decomposed granite walkway which will direct flow to the bioswales, and
    - Trash screens at drain inlets within the project site.
    - The proposed facilities provide pre-treatment of stormwater prior to entering the storm drains by screening trash to prevent it from entering the storm drain as well as providing biofiltration of the flow.
    - The Walkway/Bike Path project will also provide an underserved community with a valuable community recreation facility.
    - Costs of approximately $4.5 million.

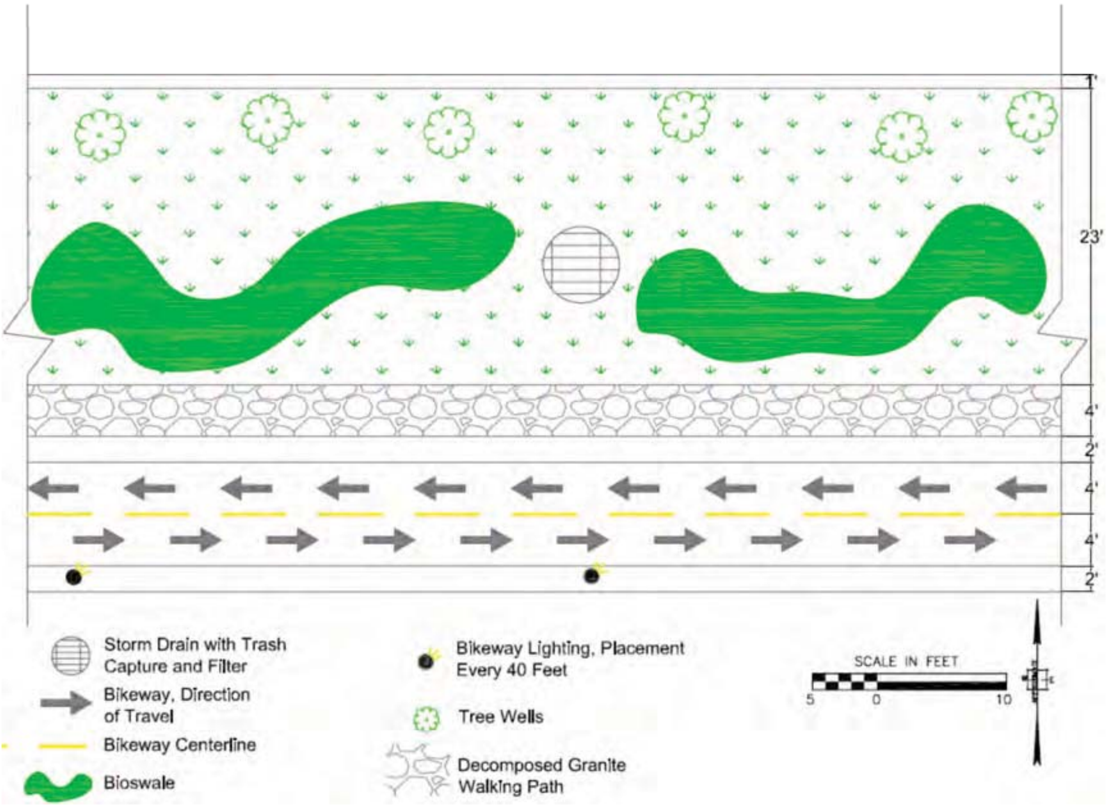


Figure 1-8: Cabrito Paseo Conceptual Plan

- Los Angeles Zoo Parking Lot
    - The various best management practices (BMPs) employed throughout the project site will form the educational framework of the parking lot as an exhibit space, providing the Zoo's 1.5 million annual visitors with information about environmental conservation, ecological sustainability, native planting techniques, and alternative energy sources.

© ASCE 2014

  - The parking lot is the Zoo's first interaction with visitors and an opportunity to provide an exhibit that is at the cutting edge of environmental technology.
  - Additionally, solar trees, free standing photovoltaic panels, will be installed throughout the parking lot to harness passive solar energy.
  - The parking lot will also encourage alternative methods of transportation by providing easy access to bicycle paths and public transportation.
  - Costs of approximately $14 million.

Figure 1-9: Los Angeles Zoo Parking Lot

- Rory M. Shaw Memorial Wetlands Park (formerly Strathern Wetlands)
  - The Rory M. Shaw Memorial Wetlands Park Project converts a 30-acre gravel pit located in the Community of Sun Valley, Los Angeles to a multipurpose facility dedicated to stormwater retention, treatment, and reuse and is critical to the overall success of the Sun Valley Watershed Management Plan which was developed through a stakeholder process to solve the chronic local flooding problem in the Sun Valley Watershed.
  - The project consists of developing retention ponds and/or constructed wetlands in the deeper sections of the facility to capture and treat storm flows generated from a Capital Flood event while preserving the shallower sections of the facility for developing terraces of different depths for the use of recreation and wildlife habitat.

© ASCE 2014

- Benefits can be realized by acquiring the Strathern Pit, a dormant gravel quarry, capturing upstream runoff, conveying the flows through treatment wetlands, and pumping the treated water to the nearby Sun Valley Park for infiltration or to be used onsite to support treatment wetlands.
- The remaining open space, at project completion, is being restored ecologically and enhanced with recreational amenities to provide opportunities for wildlife habitat and to serve as a recreational and educational resource to the local community.
- Costs of approximately $22.5 million.

Figure 1-10: Rory M. Shaw Memorial Wetlands Park Conceptual Site Plan

- Inner Cabrillo Beach Bacterial Water Improvement Project
    - Project Component 1: A previous partial bird exclusion structure erected in 2001 was shown to have a significant positive effect, but violations have still been at high, unacceptable levels. This project component would extend a bird exclusion structure over the entire beach using a more esthetic design with much fewer poles.
    - Project Component 2: Remove the old outfall as a potential conduit, and investigate and repair the sources of sanitary contamination up on Stephen M. White Drive immediately above Inner Cabrillo Beach as additional transport paths to the beach other than the old outfall may exist.

© ASCE 2014

- Project Component 3: Re-contour the beach to raise the elevation to +9 feet MLLW and replace the sand with new, coarse beach sand to increase the porosity.
- Project Component 4: Develop a resource management plan that would include management policies and practices that would optimize these resource values. This plan would include both aquatic and landside resources management, and would include a management plan for eelgrass; clean and deepen the immediate near-shore area out to the swim buoy line to remove eelgrass and fine sediments and replace with coarser sand which will prevent erosion of fine sediments and also enhance the swim area by provision of a sand bottom free of eelgrass.
- Project Component 5: Extensive hydrodynamic modeling and field experiments have shown that circulation at the beach face is poor, but that water mixing and enhancement in circulation by means of a local pump can be effective in reducing bacterial concentrations at the beach face. Circulation would be enhanced in two ways, one being removal of the groin extension at the northern end of Inner Cabrillo Beach yielding a small improvement, and secondly the installation of a circulation pump(s) just outside the swim buoy line at Inner Cabrillo Beach.
- Project Component 6: Storm drain overflow still drains over the beach sand in the southern corner of Inner Cabrillo Beach and discharges occur during the larger rain events. The stormwater outfalls from the northern area (that drain a large area in San Pedro) will be diverted out of the near-shore Harbor waters to the high energy area outside the breakwater.
- Costs of approximately $16 million.

© ASCE 2014

City of Los Angeles – the Green Blue City One Water Program, Part 4 of 5: Pollutant Load Reduction 2 – Public Green Infrastructure continued, LID Ordinance for Private Green Infrastructure

Adel Hagekhalil, P.E., Shahram Kharaghani[1], P.E., Wing Tam[1], P.E., Richard Haimann[2], P.E.; Ken Susilo, P.E.[3]

[1]City of Los Angeles Bureau of Sanitation, [2]HDR, [3]Geosyntec

1 Pollutant Load Reduction Continued

1.1 Public Green Infrastructure through Proposition O Continued

Below are more of the proposition O and related green infrastructure projects that provide a water quality and water supply benefit. Many provide other benefits such as habitat restoration, recreation, aesthetics, urban heat island reduction, and potentially community revitalization benefits as well.

- Wilmington Drain Multi-Use Project
    - This project will enhance Wilmington Drain via a multi-step approach including stormwater screening and treatment,
    - Enhanced public access,
    - Bank stabilization, and
    - Native vegetation restoration.
    - Stormwater quality will be improved using netting systems that will trap trash and debris and utilize natural materials and well-planned landscaping features, avoiding the need for destructive clearing of the channel.
    - The project will create a public park to provide recreational opportunities for the surrounding disadvantaged communities.
    - The park will include multiple amenities including a fenced off-leash dog area and
    - Decomposed granite trails with educational signage will provide learning and passive recreational opportunities.
    - The site furnishings will include tree-shaded benches, drinking fountains, picnic tables that offer visible seating and safe gathering spaces.
    - Permanent restrooms are proposed to provide an alternative to the observed use of the channel for such needs.
    - Costs of approximately $21 million.

© ASCE 2014

Figure 1-1: Wilmington Drain Conceptual Site Plan

- Machado Lake Ecosystem Rehabilitation Project
    - The broad goal of the Machado Lake Ecosystem Rehabilitation Project is to improve the water quality conditions, visual aesthetics, and the biological diversity of the ecosystem to attain and sustain its desired uses and characteristics (i.e. recreational fishing, wildlife habitat, environmental education), and to meet Total Maximum Daily Load (TMDL) requirements and other water quality targets.
    - This effort will be accomplished through integrated ecological and engineering strategies and solutions involving watershed-based management approaches,
    - In-lake rehabilitation and streambed assessment techniques,
    - Riparian system enhancements, and
    - Treatment best management practices (BMPs) at strategic areas in the park.
    - Costs of approximately $100 million.

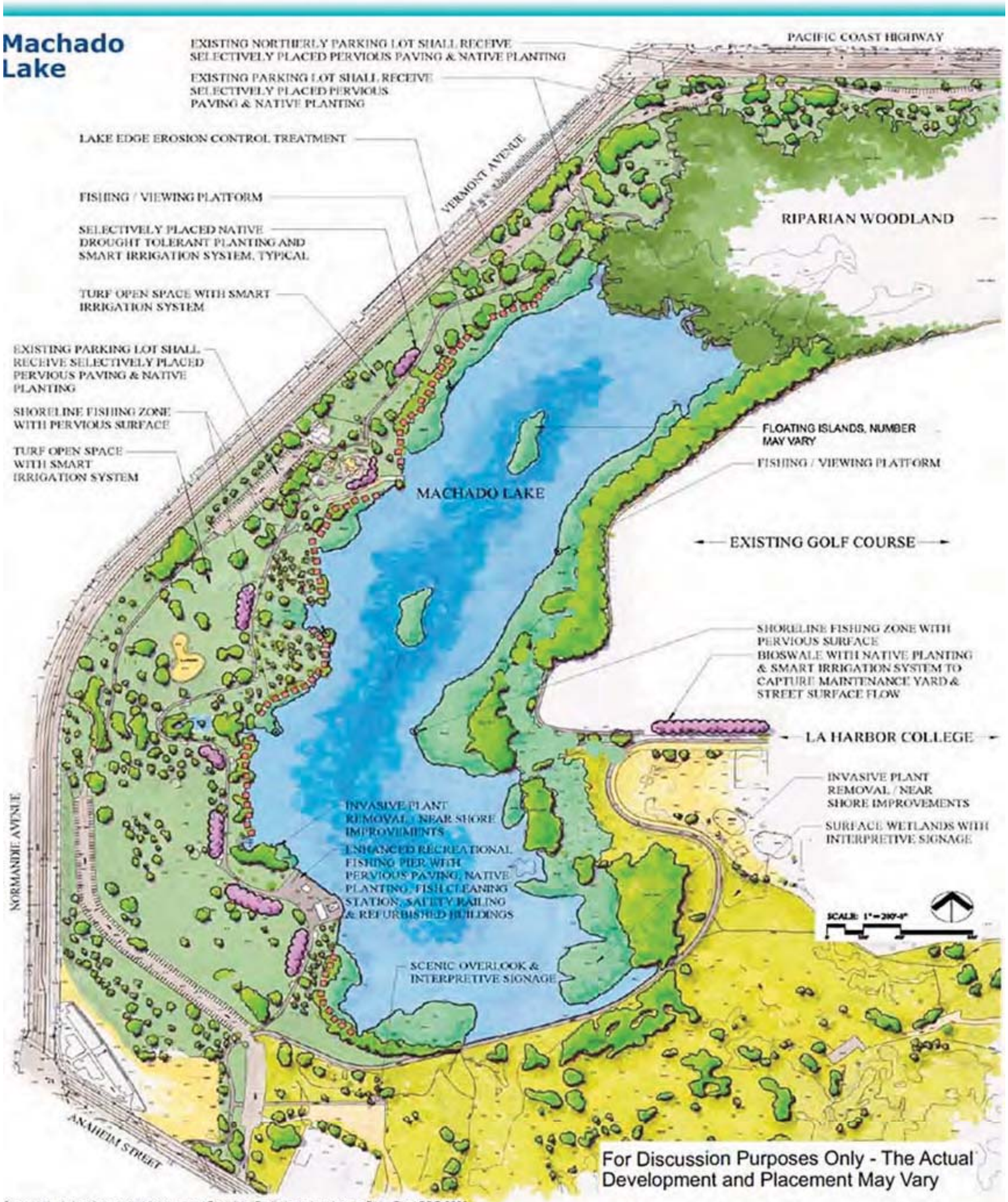


Figure 1-2: Machado Lake Conceptual Site Plan

- Rosecrans Recreation Center Stormwater Enhancements
    - Stormwater enhancements include a "smart" irrigation system,
    - Porous pavers in an existing parking lot and a new parking lot (non-Prop O funded), bioswales,
    - Vegetated retention basins,
    - Decomposed granite pathways,
    - A synthetic soccer field, and

© ASCE 2014

- A cistern beneath the soccer field.
- The site will also be graded and landscaped to provide better drainage at the recreation center and to direct flows to the treatment bioswales and retention basins.
- Costs of approximately $6.8 million.

Figure 1-3: Rosecrans Recreation Center Improvements Conceptual Site Plan

- Peck Park Canyon
  - New catch basin
  - New catch basin, connector pipe, and outlet structure

© ASCE 2014

- Restored trails
- Remove exotic invasive vegetation
- Install trash cans, signs, and barriers
- Costs of approximately $6.2 million.

Figure 1-4: Peck Park Canyon Restoration

- Coastal Interceptor Relief Sewer
  - 4,500-foot gravity relief sewer between Will Rogers State Beach and the City of Santa Monica (near the Annenberg Community Beach House, 415 PCH).
  - About 3,100 feet of the sewer will be built on PCH, and 1,400 feet in the parking lots for Will Rogers Beach and Santa Monica Beach Club
  - This is needed to support about 8 Low Flow Diversions that divert dry weather urban runoff from the beaches to the Hyperion wastewater treatment plant.
- Low Flow Diversions
  - To increase its efforts to remove bacteria and other pollutants from urban runoff and keep them from reaching Santa Monica Bay, the City of Los Angeles is upgrading seven existing Low Flow Diversion systems (LFDs), and building one new one.
  - The current LFDs take runoff and discharge it to the sewer system during the spring and summer dry season only. The upgrades will increases capacity and system reliability, allowing the LFDs to function year round.
  - Costs of approximately $39 million.
- Temescal Canyon Stormwater BMPs.

© ASCE 2014

- Project location: In and adjacent to portions of Temescal Canyon Road and Temescal Canyon Park in Pacific Palisades, near the intersection of Pacific Coast Highway and Temescal Canyon Road. Also along a portion of PCH, south of the intersection on the east side of the road;
- A stormwater pre-treatment facility will remove trash, debris, coarse sediment, oil, and grease prior to downstream treatment of stormwater at the Hyperion Treatment Plant;
- All new equipment and facilities will be designed to maximize the amount of treatable dry and wet weather stormwater flows. As a result most - if not all - of the stormwater from this watershed will be kept out of the drain that flows into Santa Monica Bay at Will Rogers State Beach;
- Following the first phase of work, a disinfection system will be built to allow a portion of the treated water to be locally reused for landscape irrigation;
- Total budget: Estimated at $7.8 million (paid for by Proposition O Clean Water Bond funds)

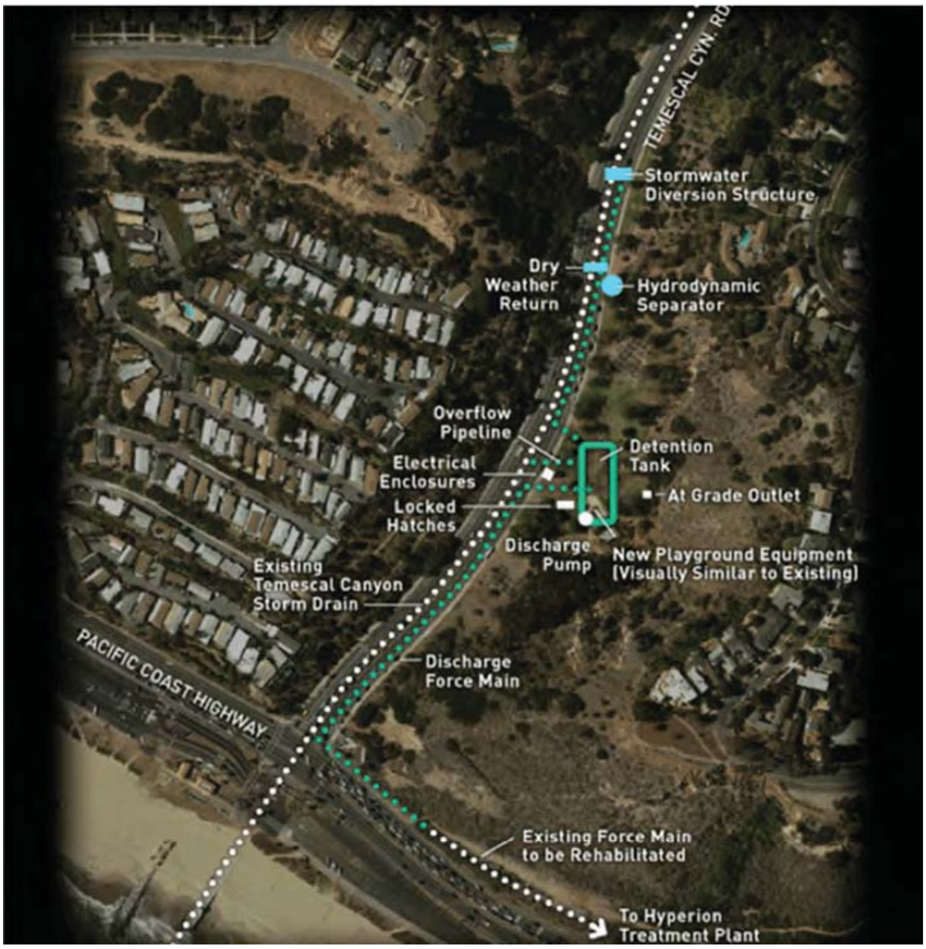


Figure 1-5: Temescal Canyon Conceptual Site Plan

© ASCE 2014

- Penmar Water Quality Improvement Project
  - Project location: Along portions of Frederick St. and Rose Ave. in Venice, adjacent to the Penmar Golf Course and under a portion of the Penmar Recreation Center Park play fields. Other project work will take place in a few local streets;
  - The first phase of the project directs some of the area's dry-weather urban runoff and wet weather stormwater to the Hyperion Treatment Plant for pollutant removal. As a result, up to nearly three million gallons (per storm event) of stormwater from this watershed that is currently untreated will be kept out of the drain that flows into Santa Monica Bay;
  - The major project components consist of a stormwater diversion structure, pumps, storm drain sewer pipes and sanitary sewer pipes, and an underground storage tank;
  - Following the first phase of work, a disinfection system will be built to treat a portion of the stormwater flow. The safe, treated water will be locally used for landscape irrigation at the Penmar Golf Course, Penmar Recreation Center Park, and Marine Park.
  - Costs of approximately $24 million.

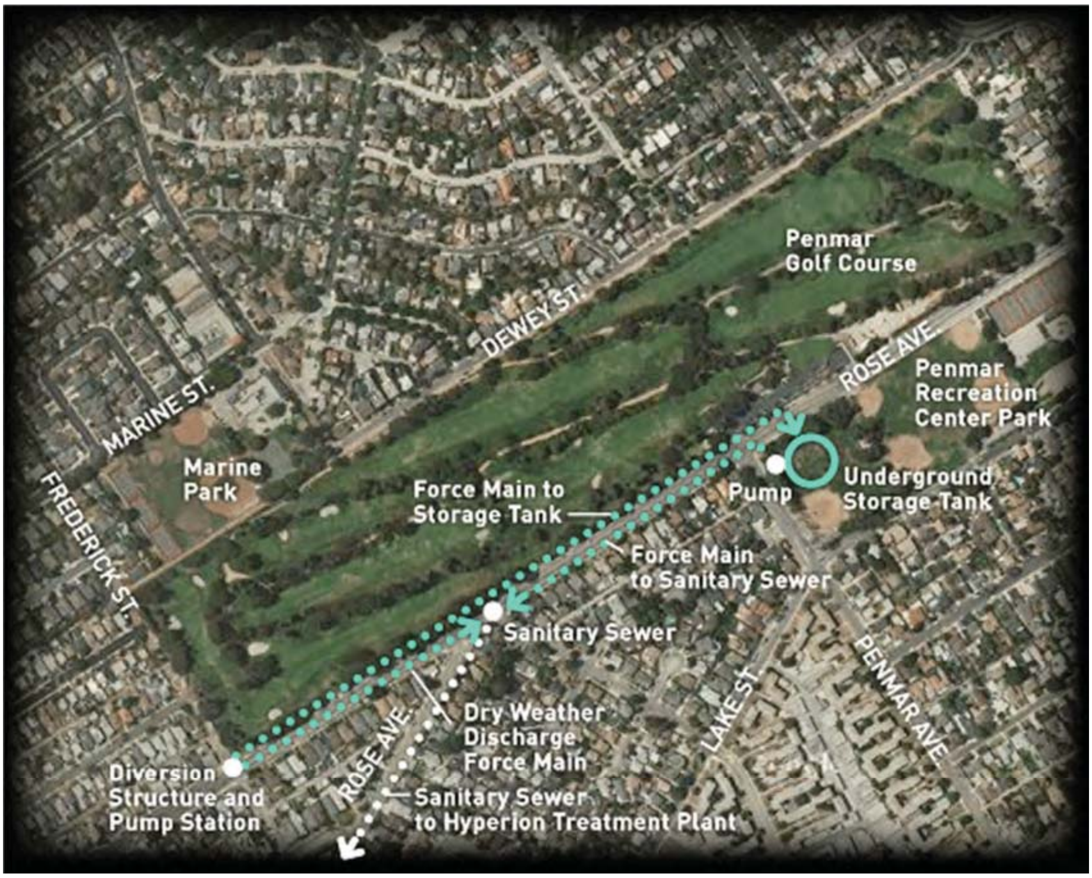


Figure 1-6: Penmar Water Quality Improvement Project Conceptual Site Plan

© ASCE 2014

- Laurel Canyon Green Street
    - The Laurel Canyon Boulevard Green Streets Project (Project), in the San Fernando Valley area of Los Angeles, is a Low Impact Development (LID) project that will collect runoff from a 123-acre drainage area and infiltrate it to underlying soils in the San Fernando Groundwater Basin (SFB).
    - Stormwater and urban runoff flowing along the east side of Laurel Canyon Boulevard will be directed into parkway swales allowing the water to be captured and infiltrated into permeable soils below.
    - Stormwater and urban runoff that flows along the west side of Laurel Canyon Boulevard and along the north and south sides of Kagel Canyon Street, will be directed into a dry well system at the west end of Kagel Canyon Street where it terminates at Interstate 5.
    - In addition to water quality and water supply benefits, the project will also contribute to the alleviation of local flooding and provide educational opportunities to local residents, including the middle school adjacent to the Project site, regarding watershed issues and environmental stewardship.
    - Costs of approximately $2.5 million.

- The Broadway Neighborhood Greenway Project
    - The Broadway Neighborhood Greenway Project was developed by the Water Replenishment District of Southern California and the City of Los Angeles Bureau of Sanitation to realize the water supply and water quality benefits from a stormwater capture project in Los Angeles.
    - The project area is located within a 193-acre subcatchment of the Los Angeles River watershed, in the University Park Neighborhood.
    - The prominent land use type in the watershed is high-density residential along with larger industrial, commercial, and transportation areas.
    - The primary objectives of the project are
        - 1) to assist the City of Los Angeles in compliance with the LA River TMDLs for bacteria, nutrients, trash and metals set forth by the Los Angeles Regional Water Quality Control Board for the Los Angeles River Watershed, and
        - 2) to augment groundwater recharge to the Central and West Coast Basins.
    - The project will achieve these benefits through the design and implementation of four levels of stormwater BMPs:
        - residential,
        - parcel-based BMPs for 8 acres;
        - neighborhood-scale BMPs for 16 acres;

- green street commercial BMPs for 4.5 acres; and

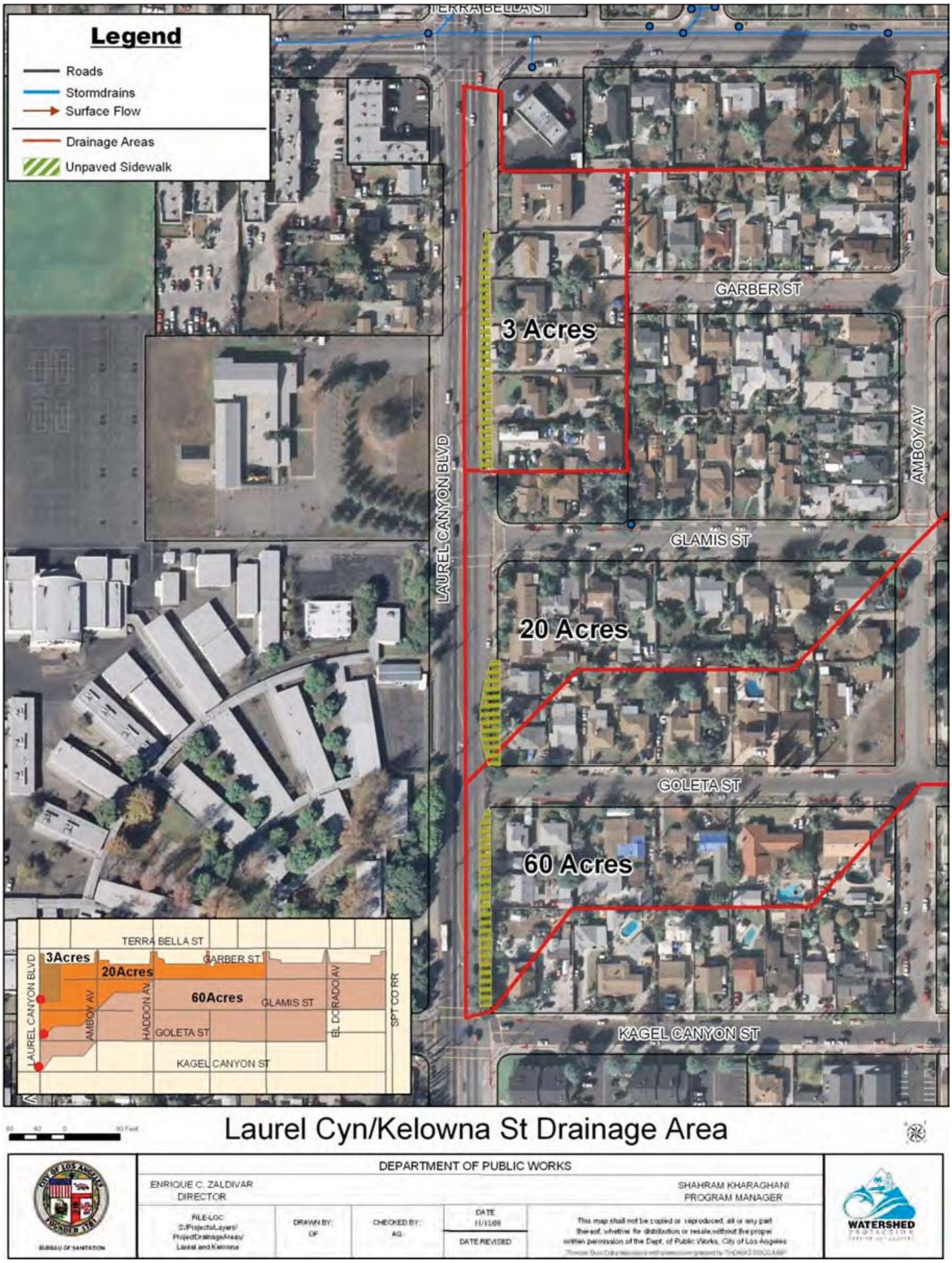


Figure 1-7: Laurel Canyon Conceptual Site Plan

© ASCE 2014

    - a sub-regional scale BMP for 29 acres of mixed land use surface runoff.
  - The residential, commercial, and neighborhood BMPs will capture and infiltrate dry-weather flow and stormwater runoff up to the ¾ inch design storm event.
  - The sub-regional BMP will capture runoff from storms greater than the ¾" inch design storm event for 29 acres, excluding the volume captured by the distributed upstream BMPs.
  - Concept designs include
    - a combination of dry wells,
    - rain gardens,
    - parkway swales,
    - infiltration trenches, and
    - a large-scale subsurface infiltration facility.
  - The sub-regional BMP will also receive dry-weather flows from 193 acres of mixed land uses by connecting to, and receiving flows from, the existing storm drain network located beneath Broadway.
  - Costs of approximately $7.6 million
- Albion Riverside Park Project
  - This project converts an unused dairy facility into a park, recreation area, and stormwater capture and treatment facility. The new park will connect an existing park with the Los Angeles River and create a recreation area on the banks of the Los Angeles River. This project fits the Los Angeles River Revitalization Plan Elements.
  - The new park will be 6 acres in size.
  - The park BMPs will treat runoff from 233 acres of upland area.
  - The park will include
    - a soccer field
    - fitness equipment
    - walking/biking/jogging paths
    - playground equipment
    - bio-infiltration basins
    - bioswales
    - subsurface storage and infiltration facilities
    - a meadow area
    - green street elements
    - a hydrodynamic separator
    - porous paving
    - native California vegetation throughout.

© ASCE 2014

- The park will provide water quality, recreational, habitat, and aesthetic benefits.
- Costs of approximately $17 million.

Figure 1-8: Albion Riverside Park Conceptual Site Plan

As the EWMPs are completed, projects necessary to capture the 85th percentile storm or achieve waste load allocations will be identified. They will be a combination of minimum control measure expansion, reliance on new and re-development programs, and public projects such as those constructed under proposition O.

1.2 Low Impact Development Ordinance for Private Green Infrastructure

In 2012, the City of Los Angeles passed a Low Impact Development (LID) ordinance requiring all new and redevelopment to make use of LID as their BMP to capture and infiltrate or use onsite the 85th percentile storm, if feasible. Figure 1- shows the developer decision and City approval process for complying with the LID ordinance.

This ordinance is one of the more stringent in the U.S. in that it:

- Captures projects where more than 500 square feet is being modified,
- Requires that one prove that it is infeasible to implement various LID techniques before being allowed to use a non-LID BMP.
- Defines LID as preventing the release of the 85th percentile storm from the parcel.
- Requires a high efficiency biofiltration system if LID is infeasible.

© ASCE 2014

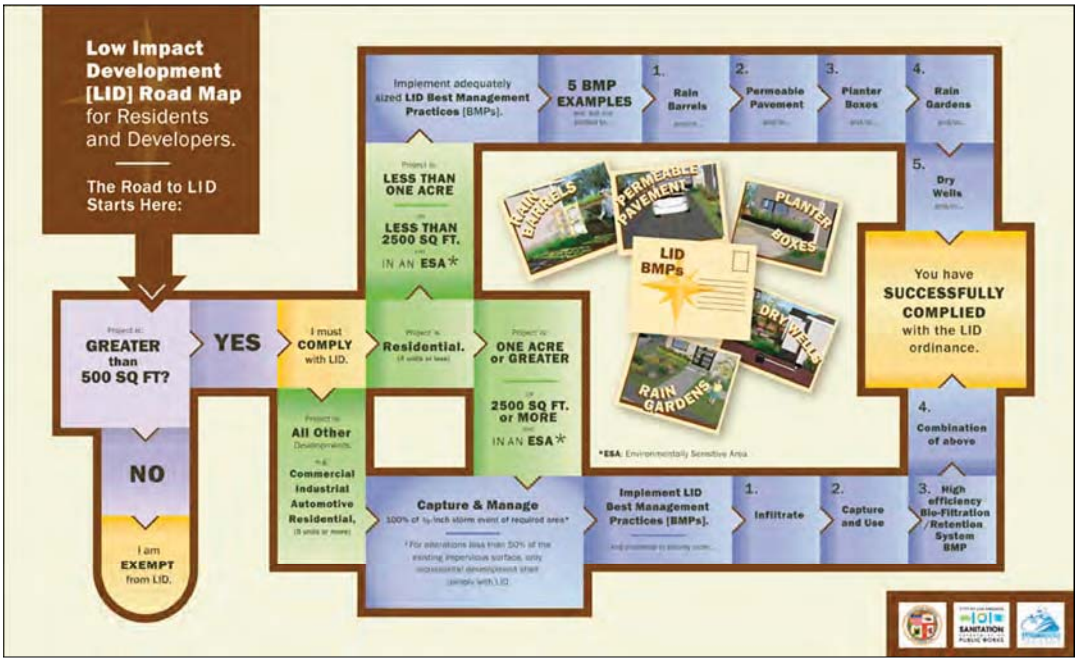


Figure 1-9: City of Los Angeles Low Impact Development Ordinance Process (http://www.lastormwater.org/green-la/low-impact-development/)

The City staff in the Watershed Protection Division worked closely with their counterparts in the Division of Building and Safety that issues building permits and enforces the LID ordinance to ensure that building codes were compatible with the LID ordinance.

With this ordinance in place, the EWMPs will take under consideration private development capturing the 85th percentile storm where feasible as one element of meeting the water quality goals of the EWMPs.

© ASCE 2014

City of Los Angeles – the Green Blue City One Water Program, Part 5 of 5: Los Angeles River Revitalization, Big Picture – One Water System

Adel Hagekhalil, P.E., Shahram Kharaghani[1], P.E., Wing Tam[1], P.E., Richard Haimann[2], P.E.; Ken Susilo, P.E.[3]

[1]City of Los Angeles Bureau of Sanitation, [2]HDR, [3]Geosyntec

1 Los Angeles River Revitalization Plan

In 2007, the City of Los Angeles published a master plan for revitalizing the Los Angeles River corridor. This plan showed a vision for modifications to the river to achieve multiple benefits and revitalize the land around the river. Figure 1-1 shows an example project vision near downtown Los Angeles. The Los Angeles River along the planning corridor is generally concrete lined, either along the bottom and sides, or along the sides. Adjacent to the River are industrial properties, many of which are underutilized, railroad alignments, and streets. The general planning vision was to modify channel cross sections where possible to reduce water velocities, allow for retention of water to provide recreational and habitat spaces, acquire adjacent property to provide attractive recreational features to attract activities, and provide planning guidance for private development of other parcels that would revitalize the river corridor. In total, 32 miles of river corridor are within the revitalization plan.

Figure 1-1: Example Los Angeles River Revitalization Project Vision

© ASCE 2014

Upon adoption of the plan, a non-profit organization called the Angeles River Revitalization Corporation formed to develop projects along the river that fit within the planning elements and spur the redevelopment of the corridor. The Albion Park project discussed above is one of the projects being developed within the planning elements. The US Army Corps of Engineers has been working to complete a feasibility study of a number of alternatives for modifying the channel cross-sections, to support Federal interests associated with plan elements.

Overall, as the planning elements are implemented and projects constructed, this will improve local water supply, reduce pollutant discharges to downstream reaches of the river, increase recreation, restore habitat, and provide a boost to real estate values and economic activity in the region.

2 The Big Picture – One Water System

As shown in this paper, the City of Los Angeles is working to meet multiple goals with its water management program to use water as wisely and efficiently as possible. The City has adopted the paradigm that water, in any form, is a precious resource that should not be wasted. To put the vision all together in a series of planning elements, the City is moving forward to:

- Prevent stormwater from leaving the City. Capturing and infiltrating it wherever possible and/or using it on site where possible.
- Recycling as much of its wastewater as it can cost-effectively recycle for non potable and indirect potable use.
- Restoring its groundwater basins to increase the storage capacity and yield of those basins lost to contamination.
- Conserving water through demand reduction incentives.

By implementing these planning elements, the City is driving itself toward water sustainability. It will reduce pollutant discharges, reduce reliance on imported water, lower energy consumption from water transfers, reduce wastewater discharges, and capture more co-benefit values from the water projects it invests in: recreation, habitat, and community revitalization.

At the larger proposition O projects, communities around those facilities such as the South Los Angeles Wetlands Park, Echo Park, and the like are already experiencing revitalization through the use of those facilities.

One key note is that these goals are being achieved concurrently by multiple departments within the City and by multiple agencies outside the City. They are all working toward the same goal, communicating regularly, and collaborating on projects through an Integrated Regional Planning process. Figure 2-1 shows projected water sources for the City of Los Angeles as the plans discussed above are implemented.

Demand for MWD water is expected to halve by 2035. As more local stormwater is captured, pollutant loads to the receiving waters are expected to be reduced to meet permit requirements as well. Finally, the nature of the projects being planned to achieve these multiple objectives are expected to improve overall community vitality and economic activity.

It is important to note that Figure 2-1 shows the projected water use in an average year. Under a dry year scenario, the percent of water purchased from MWD is expected to be approximately ½ of the total water used in Los Angeles. This is far less than the current MWD purchases, but does not end reliance on MWD supplies entirely.

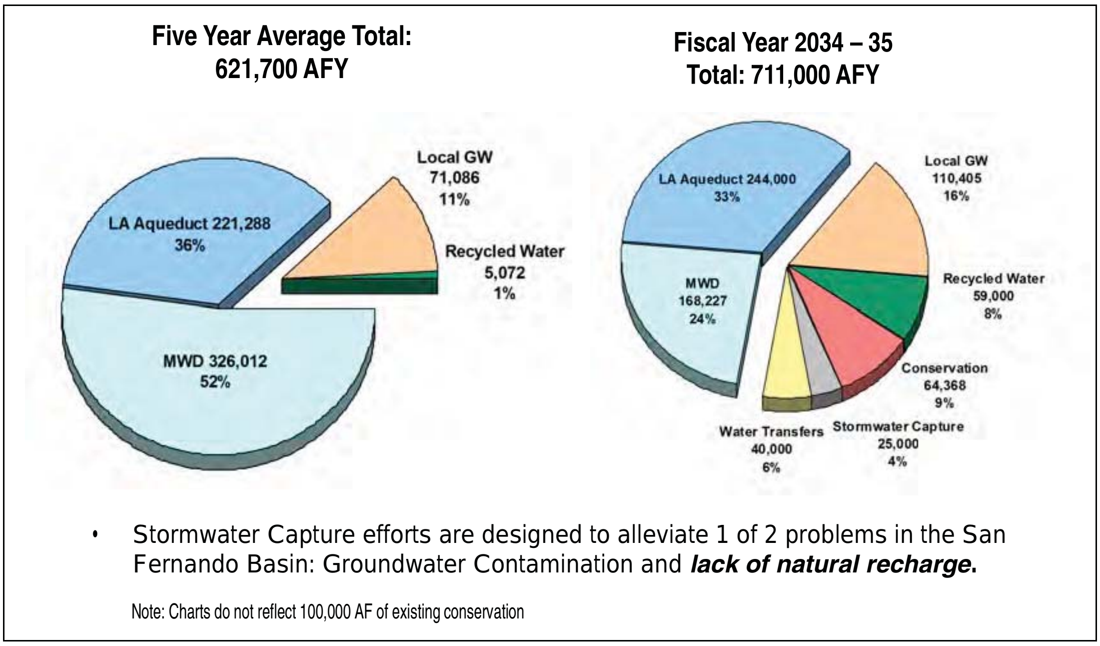


Figure 2-1: Water Supply Projections

© ASCE 2014

Analysing the Urban Metabolic Trends to Come to Terms with Ecological Wisdom: A Case Study of Dalian

Gengyuan Liu, Zhifeng Yang[*], Lixiao Zhang

State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, No. 19 Xinjiekouwai Street, Haidian District, Beijing 100875, China. Email: liugengyuan@163.com (primary contact); zfyang@bnu.edu.cn; zhanglixiao@bnu.edu.cns

ABSTRACT

Characterized by high level, multiple hierarchy and dynamical structure, cities are typical examples of "complex systems" that are combinations of components acting together to perform specific objectives and have many non-apparent and little understood characteristics. This paper describes the development of a forecasting model, named the emergy-based urban dynamic model, capable of accurately simulating the observed resource consumption, economic growth, and environmental impact of Dalian from 2000 to 2050. This model differs from previous urban emergy models by monitoring the negative effects to human well-being and ecosystem integrity in the developing urban systems. Statistical information and calibration were also considered in this dynamic emergy accounting. This study advances the temporal dynamic principles of emergy accounting through integrating upstream and downstream evaluation methods to quantify the environmental impact by addressing specific damages to human health and ecosystem's integrity and by linking such impacts to a supply-side environmental cost evaluation.

Keywords: Urban system; Emergy analysis; System dynamics; Environmental impacts, Dalian

1. INTRODUCTION

As a city is a dynamic system it is important to understand trends in energy use over time. Like the human body, the socio-economic system can be characterized by its metabolism, where energy and materials are used as input and waste as output (Odum, 1983). The metabolism approach is a powerful metaphor for the illustration of the processes that mobilize and control the flows of energy and materials through a socio-economic system. Understanding how a socio-economic system works as an ecological system will help take control of the vital links between human actions and the quality of the environment. Hence, the knowledge of human-induced energy and material flows with comparison to those of natural flows is a major step towards the design of sustainable development and ecological wisdom schemes.

Policy makers have attempted to explain trends among socio-economic systems for various indices of metabolic performance based primarily on economics density, industrial structure and efficacy and environmental impacts, with varying results.

[*] Corresponding author: Tel.:+86 10 58807951; Fax: +86 10 58800397.
E-mail address: zfyang@bnu.edu.cn (Zhifeng Yang).

© ASCE 2014

However, most of these indices have problems associated with their inability to describe the complexity of 'sustainable' development, lack of comprehensiveness, and arbitrary or subjective assumptions regarding normalization and weighting. It is important to be able to see the indicators reflecting sustainability of cities so that poor ecological performers can be identified. We use the unit of 'city' as a basis for environmental impact rank because a government's decisions affecting the state of the environment can be realistically best made at this level.

As an effective tool for system analysis, emergy, which can connect the social economic system with the ecological system, is a well-suited approach for the evaluation of an urban ecosystem composed of multiple social, economic, and ecological elements (Ulgiati et al., 1995). In fact, emergy analysis and such corresponding indicators as emergy source, emergy intensity, emergy structure, emergy welfare, and ecological economic interface, have been applied to the ecological accounting and analysis of many urban ecosystems (Lu et al., 2003; Lei and Wang, 2008; Brown and Ulgiati, 2010). These indicators are directly linked to urban ecosystems in an integrated way through the combined values of the services. Therefore, we attempted to proposal an emergy-based urban dynamic development process analysis (including flux, efficiency, and environmental impact) to determine whether the overall conditions are better (toward a sustainable path) or worse. The emergy indicators, i.e., measures of system order and stability, are used to perform an assessment of the dynamic behavior and sustainable trends of an urban system's trajectory. This study aimed to investigate the urban dynamic changes and provide insights into regional environmental protection and regional policy decision-making.

2. CONCEPTS AND THEORIES USED IN THIS WORK

To investigate the mechanisms of resource flows on urban development, ideas from the General System Theory and techniques of emergy analysis were employed to simulate urban ecological economics. This simulation dealt with the changes in an urban system over time through a developmental approach and examined the system as a complete functioning unit.

This paper describes the development of a forecasting model, named the emergy-based urban dynamic model, capable of accurately simulating the observed resource consumption, economic growth, and environmental impact of Dalian from 2000 to 2050. In the present work, the simulation procedure can be divided in the following steps (Odum and Odum, 2001): 1) draw a complex systemic diagram of the urban ecosystem using the emergy symbols; 2) account for the urban flows and stocks; 3) elaborate the mathematical representation of the wastes impacts, including ecological and economic losses, in a programming environment; 4) derive model equations from the aggregated energy systems diagram and program them into Vensim® software; 5) calibrate, validate, and run the mathematical model considering the specific scenarios established; and 6) assess the dynamics of the emergy indices. In this way, it is possible to reveal the properties and performances of an urban system as a whole. The urban dynamic model integrated 9 dynamic subsystem models.

3. METHODOLOGY

© ASCE 2014

The dynamic model was integrated from 10 state variables, including Agricultural Land (LA), Agricultural Assets (AA), Ecological Land (LE), Ecological Assets (AE), Water Resource (WR), Urban Land (LU), Urban Assets (AU), Waste (W), Money (M), and Population (P). All of these state variables are linked by a coefficient k (k101, k102, …) and composed into nonlinear complex relations. A validation test was necessary and significant for checking the structure and stability of the model. Five state variables were selected for the validation, and the results were compared with the historical data from the years 1996 to 2006. The model fits the real system's behavior with a relative error of < 10%.

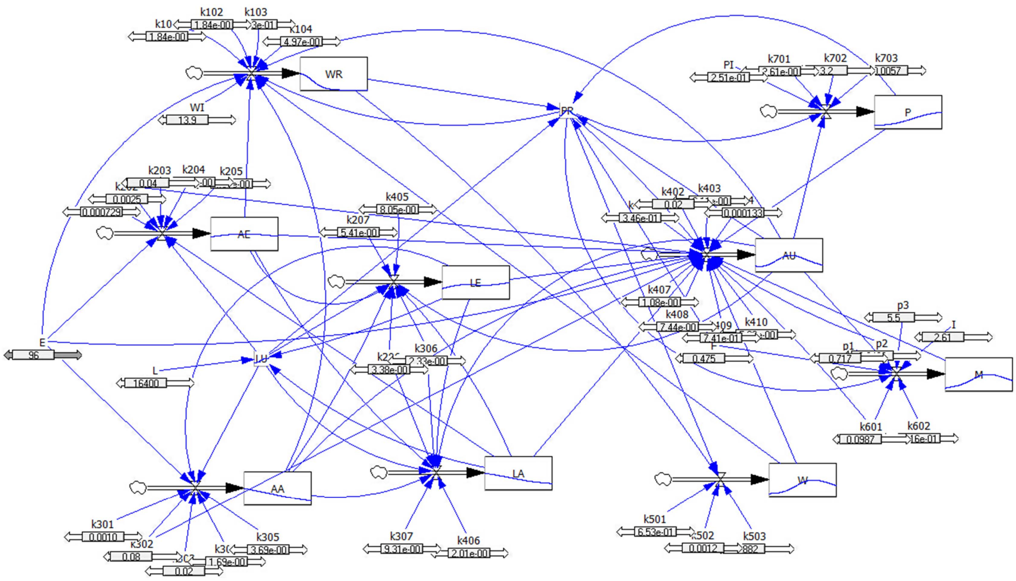


Figure 1. Emergy-based urban dynamic model in Vensim

(1) Land (land conversions)

The occupied areas of each type of land, including ecological, agricultural, and urban land, are changing. The equation that defines Ecological Land is: dLE/dt = k205*LA*AE + k206*LU*AE - k104*LE*AA - k405*LE*AU, where k205*LA*AE and k206*LU*AE describe the land transition from LA to LE and from LU to LE, while k104*LE*AA and k405*LE*AU describe the land transition from LE to LA and from LE to LU. The conversion of land type is bidirectional in this model. Total area = LE + LA + LU. Over the last decade, rapid urbanization has resulted in serious loss of land resources. Land occupation for landfill and disposal also resulted in land loss (irreversibly degraded). Dalian's urban area has increased continuously, which encroaches on large amounts of agricultural and ecological land. The Dalian settlement area in 2010 was 1.25 times more than in 2000, while the agricultural land decreased by 32%. These encroachments are mainly caused by new urban construction developments around the satellite towns at the transition belt between the city center and the suburbs.

(2) Assets (urban wealth and infrastructure)

© ASCE 2014

AEs rely on the input of renewable energy (R). In integrated urban planning, green-spaces (which benefit urban communities in an ecological, esthetical, and economical sense) are a significant consideration. The equation is: dAE/dt = k201*AE*R - k202*AE - k203*AE - k205*AE*LA - k204*AE*LU - k207*AE*W. Both the growth of LU (k206*AE*LU) and LA (k205*AE*LA) will reduce the accumulation of AE. Similarly, AA vary as AE. The dynamic equation is: dAA/dt = k101*AA*E - k102*AA - k103*AA - k104*AA*LE - k105*AA*LU. As the core of the urban subsystem, AUs result in a fairly complicated balance with other subsystems; equation is: dAU/dt = k401*PR + k202*AE + k302*AA + k601*M/p^2 - k409*E*LE*AE - k410*E*AA*LA - k404*AU*P - k403*W - k402*AU - k407*LE*AU - k408*LA*AU. After decades of reforms toward a free market economy, Dalian is in the midst of extraordinary economic development. However, the economic growth in the past decade has largely been accomplished at the expense of environmental degradation. Dalian is facing the challenge to decide whether the city can sustain such rapid growth based on its available resources and existing environmental capacity. Therefore, modification of Dalian's urban functions and economic structure in the context of China's total urban system is considered necessary and pressing.

(3) Water resources

As a well-known city lacking water resources due to the combined effects of scarce water availability, poor water quality, rapid growth of demand, and inefficient wastewater treatment, Dalian has a dilemma between continuous urban expansion versus limited water resources and environmental deterioration. The dynamic equation of water resources is: dWR/dt = k301*R*AA*AU + k302*R*AE*AU + WI - k303*PR - k104*WR. Diverse strategies have been recently implemented, involving a water diversion project from the Yangtze River and a pricing promotion for more efficient water use. In addition, water consumption has been reduced by virtue of economic structure adjustments and the application of water conservation technology. However, due to rapid urbanization and climate change, the risk of a water crisis is more severe than ever. Water shortage has become a serious constraint to Dalian's sustainable development.

(4) Population (population migration)

Largely due to the one-child family policy in the past several decades, Dalian's population growth has remarkably slowed in recent years. From 2005 to 2010, the natural growth rates were in the range of 6% to 12%, which dramatically decreased to < 1% after 2000. The growing population of cities include natural population growth (k701*AU*P), natural decrease (k703*P), and immigration and emigration (k702*PRU*PI). In the meantime, however, characteristic of its lowest unemployment rate and the highest infrastructure expenditure among the cities across China, it is likely that Dalian will continue to be a favorable destination for the ever increasing population in China. Thus, the high net immigration rate will continue to contribute most to the fast population increase.

(5) Environment (ecosystem services and losses)

Concerning the goal of a harmonious society set by the government, environmental issues have recently gained great importance. At this point, we must find a way to "internalize" the types of "externalities" and place emphasis on the impact of emissions on an ecosystem and human integrity by transferring these losses to the system accounting. In this study, a preliminary damage assessment of losses was performed according to the framework of the Eco-Indicator 99 assessment method (Goedkoop and Spriensma, 2000). Such methods, like all end-point life cycle impact assessment methods, suffers from very large uncertainties intrinsically embodied in its procedure for assessment of final impacts. Yet, it provides a preliminary—although uncertain—estimate of impacts to be used in the calculation procedure of total emergy investment. Damages to natural capital are expressed as the Potentially Disappeared Fraction (PDF) of species in the affected ecosystem, while damages to human health are expressed as Disability Adjusted Life Years (DALY). Six kinds of environmental impacts are considered in this study, which include carcinogenic effects on humans, respiratory effects on humans caused by organic substances, respiratory effects on humans caused by inorganic substances, damages to human health caused by climate change, damage to ecosystem quality caused by ecotoxic emissions, and damage to ecosystem quality caused by the combined effect of acidification and eutrophication. Thus, we pointed out the nature of emergy losses (L) associated with process waste (w) generation. The waste treatment system could effectively reduce waste (not to zero) through additional resources input. The human and natural capital emergy losses after waste treatment are denoted as $L_{w,1}^{*}$ and $L_{w,2}^{*}$. Furthermore, the damage associated with solid waste disposal can be measured by land occupation and degradation, which is denoted as $L_{w,3}$. The additional emergy investment for treatment is denoted as U_w and should, in principle, be lower than the damage-related losses $L_{w,n}$, to be feasible and rewarding. The waste treatment system is designed to recycle and reuse part of the emissions (flow F_b) through the use of eco-technologies. Such a recycle flow should allow a proportional decrease of the total emergy cost (U) by decreasing the use of local nonrenewable resources or by decreasing imports. Using concepts from E.I. 99 to quantify a process impact on ecosystems and human health has the advantage that the assessment relies on damages that can, in principle, be measured or statistically calculated. Unfortunately, the available data in these ecological models are restricted to Europe (in most cases to The Netherlands) and their application to assess other countries requires adjustments and calls for urgent database improvement. Moreover, the dose-response relationship considered in the Eco-indicator-99 is linear instead of logistic. The latter characteristics suggest the method can only be applied to slow changes of pollutants concentration and are not suitable for large emissions fluctuations like environmental accidents.

The algebraic expressions, in addition to the difference equations listed below provide the value of inputs, storages and flows used in model calibration.

Table 1. Spreadsheet for the equations

Description	Variable	Equation
Ecological Assets	AE[i]	dAE/dt=k201*AE*E-k203*AE-k202*AE-k204*AE*LA-k205* AE*LU
Agricultural	AA[ii]	dAA/dt=k301*AA*E-k303*AA-k302*AA-k304*AA*LE-k305

© ASCE 2014

Assets		*AA*LU
Urban Assets	AU[iii]	dAU/dt=k401*PR+k202*AE+k302*AA+k601*M/p2-k409*E*LE*AE-k410*E*AA*LA-k404*AU*P-k403*W-k402*AU-k407*LE*AU-k408*LA*AU
Ecological Land	LE	dLE/dt=k206*LA*AE+k207*LU*AE-k306*LE*AA-k405*LE*AU
Agricultural Land	LA	dLA/dt=k306*LE*AA+k307*LU*AA-k206*LA*AE-k406*LA*AU
Urban Land	LU	LU=L-LE-LA
Water Source	WR	dWR/dt=k101*E*AE*AU+k102*E*AA*AU+WI-k103*PR-k104*WR*W
Waste	W	dW/dt=k501*PR-k502*WR*W-k503*W
Population	P	dP/dt=k701*AU*P+k702*PR*PI-k703*P
Gross Domestic Product	M	dM/dt=k602*PR*p1+AU*I-k601*M-F*AU*p3

Notes:
[i] The ecological assets storage (AE+AA) was assumed to be the renewable emergy flow in 2000 (1.03E+21 sej) accumulated during the last 300 years (topsoil creating time); resulting in 3.1E+23 sej that represent the assets built by emergy accumulation. AE=LE/(LE+LA)*(AE+AA);
[ii] The ecological assets storage (AE+AA) was assumed to be the renewable emergy flow in 2000 (1.03E+21 sej) accumulated during the last 1000 years; resulting in 3.1E+23 sej that represent the assets built by emergy accumulation. AE=LA/(LE+LA)*(AE+AA);
[iii] The urban assets storage (AU) was assumed to be the total emergy used in the city in 2000 (5.85E+23 sej) minus the renewable emergy flow for the same year (1.03E+21 sej) accumulated during the last 20 years; resulting in 1.17E+26 sej that represent the assets built by emergy accumulation.

The constraint functions are constructed in light of the corresponding objectives of the year 2050 described in the Dalian urban overall planning, of which some details are tabulated in Table 1.

Table 1. Major indices of the target planning year 2050 of Dalian

Population （million）	Labor force (million)	Green-space coverage rate (%)	Waste control fee (100 million yuan)	Reinvestment ratio (%)	Water consumption (billion m^3)
18.0	10.5	44.0-48.0	40.0	60	5.2

All the calibration methods and pathway coefficients rates for the derived calibration values derive from our previous work (Liu et al., 2011). Pathway coefficients, labelled as k's in this model, indicate how much flow there is on a pathway in terms of contributing forces or concentrations. Excel spreadsheets were used for calculations, and the names of sources, stocks, and flows correspond to the energy diagram, as well as to the basic program used for modeling.

© ASCE 2014

4. Results

The available statistical data for Dalian were used to calculate the emergy flows in our dynamic model. These basic data mainly derive from our previous work (Liu et al., 2011).

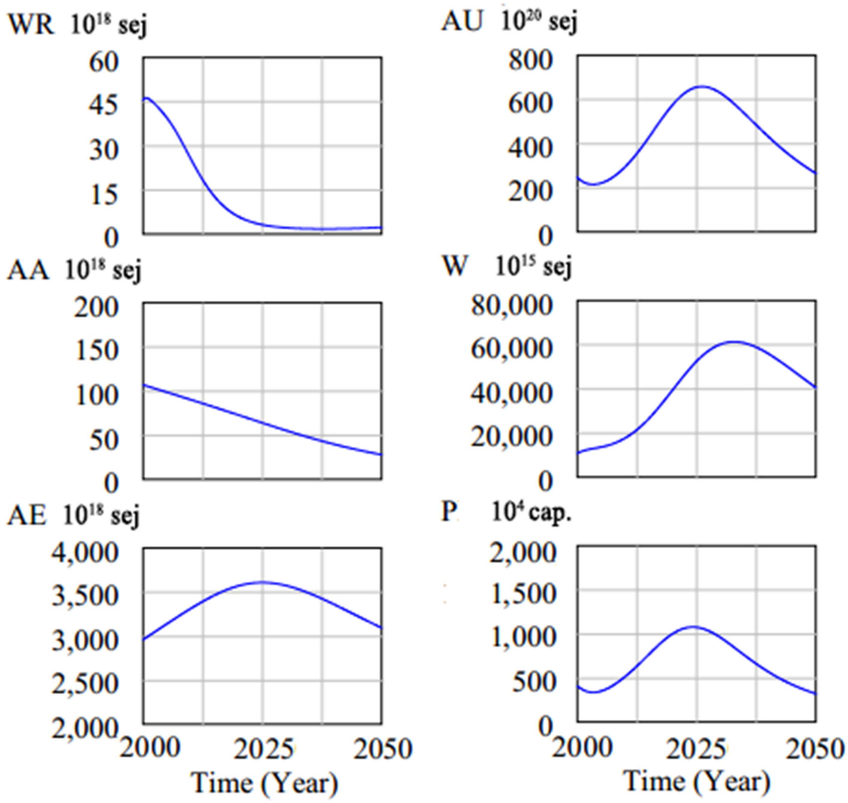


Figure 2. Simulation results of the water resource (WR), urban assent (AU), agricultural area (AA), waster (W), ecological assent (AE) and population (P)

The results show that (1) the rapid increase of residential and commercial land use causes urban sprawl that is the extension of the urban perimeter, which cuts further into available productive land and encroaches upon important ecosystems. (2) the urban assets in Dalian increase rapidly (an inverted U pattern), which suggests the development of urban infrastructure facilities and the improvement of housing conditions for Dalian residents with are constrained by resource supplies. (3) the trends in AU loss reflect what may be termed a "crescendo effect" followed by a successive increase of AU and population. These trends indicate that the economic loss related to potential damages to human health will have no improvement, or aggravate, even after the slightly reduction in pollution emissions.

The challenge for integrating the ecological and economic losses into a strategy of urban sustainable development needs to be addressed more deeply to achieve a strategy where environmental revenues and losses can be suitably balanced in order to manage or limit the growth of the economy. This should be an important role of

© ASCE 2014

urban policymakers as an effort to secure a solid foundation for long-term urban sustainable wellbeing. We followed Huang and Chen's hypothesis (2005) and made several minor modifications of: 1) the land occupation for landfill and disposal, which results in land loss (irreversibly degraded); and 2) calculating the negative effect of wastes for emergy accounting. We emphasized the determinants of human health and ecosystem integrity in the urban development process according to the framework of the Eco-Indicator 99 for monitoring the negative effects of wastes. Our purpose was to gather information that would allow policy makers to manage systems with the goal of encouraging desirable economic and social tendencies while maintaining long-term environmental responsibility that leads to sustainability. We cannot know the full effects of emissions without indicators linked directly to the goals, measurable in common units and expressive of real values to the economy and society after accounting for the values of human health, society's wealth, and well-being.

This study's results could be improved performing complementary tasks, mostly obtaining some data to be included in the simulation model. The data suggested to be included is: the life cycle assessment of the purchased fuels/goods and pollution-induced damage at an urban, regional and national level. In this sense, a polycentric approach might be an alternative for the problem, which means actions at various levels with active oversight of urban, regional, and national boundaries.

Because emergy analysis is based on a single common inventory of all the system's inputs and outputs, the systematic uncertainties are simultaneously performed on all calculated data and indicators simply by allowing for variable cells for all input quantities, as well as for the associated impact coefficients (intensity factors), in the spreadsheet-based calculation procedures. Quantifying direct and indirect flows of matter and energy to and from a system permits the construction of a detailed picture of the process itself, as well as of its relationship to the surrounding environment. In this study, the main energy, commodity, and environmental flow data used are from the official data based on the internet and publicly issued yearbooks, such as the China Statistical Yearbook (which is a survey conducted each year by the China Statistical Bureau), China Agriculture Yearbook (by the China Agricultural Bureau), and Liaoning Statistical Yearbook (by the Provincial Statistical Bureau). These data meet or exceed our data quality objectives because both sampling and non-sampling errors are considered, and the reliability of the data is reported as the coefficient of variation with its standard error. Meanwhile, the baseline is chosen to avoid errors and set more accurate transformities data due to continuous corrections (Campbell, 2000; Brown and Ulgiati, 2010).

5. Conclusion

To be sustainable a system should achieve a large economic yield (not necessarily measured in monetary terms, but likely in terms of wellbeing) while causing low environmental stress. This model identified the most significant deviations of the system's trajectory to determine whether a new path may emerge toward sustainability. The results of our study will enable urban policy planners to understand these inter-linkages by addressing specific damages to human health and the ecosystem's integrity and by linking such impacts to a supply-side environmental

© ASCE 2014

cost evaluation. It particularly outlines how an urban subsystem model is linked and how some urban key factors, such as water resource and money flows, bring profound changes to the entire system.

Acknowledgements

This work is supported by the Fund for Creative Research Groups of the National Natural Science Foundation of China (No. 51121003), National Key Technology Research and Development Program (No. 2012BAC05B02), National Natural Science Foundation of China (Grant No. 41101564), the Research Fund for the Doctoral Program of Higher Education of China (Grant No. 20110003120031), the Fundamental Research Funds for the Central Universities..

References

Brown, M. T., and Ulgiati, S. (2010). "Updated evaluation of exergy and emergy driving the geobiosphere: A review and refinement of the emergy baseline." *Ecological Modelling*, 221(20), 2501-2508.

Campbell, D. E. (2000). "A revised solar transformity for tidal energy received by the earth and dissipated globally: Implications for Emergy Analysis", pp. 255-264. In M.T. Brown (ed) Emergy Synthesis: Theory and applications of the Emergy methodology. Proceedings of the 1st Biennial Emergy Analysis Research Conference, Center for Environmental Policy, Department of environmental Engineering Sciences, University of Florida, Gainesville, FL.

Goedkoop, M., and Spriensma, R. (2000). "The Eco-indicator 99: A damage oriented method for life cycle impact assessment: Methodology report." Pre. Consultans: Amersfoort, The Netherlands. <http://www.pre-sustainability.com/download /misc/EI99_annexe_v3.pdf >

Liu, G. Y., Yang, Z. F., Chen, B., and Ulgiati, S. (2011). "Monitoring trends of urban development and environmental impact of Beijing, 1999-2006." *Science of the Total Environment*, 409(18), 3295-3308.

Lu, H. F., Ye, Z., Zhao, X. F., Peng, S. L. (2003). "A new emergy index for urban sustainable development." *Acta Ecologica Sinica*, 23, 1363-1368 (in Chinese).

Odum, H. T. (1983). *Systems ecology*. New York: John Wiley and Sons.

Lei, K. P., and Wang, Z. S. (2008). "Emergy synthesis and simulation for Macao." *Energy*. 33, 613-625.

Odum, H., and Odum, E. (2001). *A prosperous way down: principles and policies*. University Press of Colorado, USA.

Ulgiati, S., Brown, M. T., Bastianoni, S. and Marchettini, N. (1995). "Emergy-based indices and ratios to evaluate the sustainable use of resources." *Ecological Engineering,* 5, 519-531.

© ASCE 2014

Decomposition analysis of carbon emissions and water consumption of urban manufacturing industry: a case in Dalian, China

Lei Chen[1], Linyu Xu[*1], Qiao Xu[1], Zhifeng Yang[*1]

[1] State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China; PH(+8610)5880-0618; FAX(+8610)5880-0618; email: leichen@mail.bnu.edu.cn, xly@bnu.edu.cn (*primary contact*), ilqq527@126.com, zfyang@bnu.edu.cn

ABSTRACT

This paper aimed to identify the effect factors of carbon emissions and water consumption of urban manufacturing industry with Dalian city of China as a case study. We selected 29 Dalian manufacturing industrial sectors, and collected the statistical data of energy and water demand from 2006 to 2010 to calculate the carbon emission intensity and water consumption. All of these 29 industry sectors could be grouped into three industrial types of labor-intensive, capital-intensive and technology-intensive industries. The carbon intensity and water intensity during this period were calculated, and LMDI (Logarithmic Mean Divisia Index) method was used to identify the effects of economic output, industry structure, carbon intensity (or water intensity) on the total carbon emissions (or water consumption) from Dalian manufacturing industry. The results showed that economic output is the main driving force of increase of both total carbon emission and total water consumption, while optimization of the manufacturing industrial structure will contribute to reduce both of them.

Key words: Low carbon; Industrial structure; carbon emission; water consumption; LMDI; Dalian

INTRODUCTION

Rapid industrial development consumes a lot of water and energy, which causes not only urban water shortage but also large amount of carbon emission (Gu et al. 2014). So it is urgent to optimize the urban industrial structure under the water constraints and low-carbon goal.

As a pillar industry of in China, manufacturing industry has always played large part in carbon emission and water consumption. Its development model of high input, high consumption leads to rapid growth carbon emissions, and industrial structure

---

*Corresponding author

adjustment and upgrading accelerate the process of industrialization, showing a significant "high-carbon" characteristic (Ren et al. 2014). At the same time, the water use efficiency of industrial water, especially manufacturing industry with high water intensity, shows an obvious gap with the developed countries (Wang et al. 2014).

In this context, this paper aims to analyze the correlation between industry development and water consumption well as industrial carbon emission, in order to solve the shortage of water resources and reduce carbon emission of manufacturing industries in Dalian, China.

METHODOLOGY

Study area and data acquisition

Taking the city of Dalian, a coastal city yet of severely water shortage(See Figure 1.) , as a case, its water resources per capital is only 604m^3, which is 25% and 6.75% of the national and the world average. Economic development is incompatible with the region's water resources, the severe contradiction between water supply and water demand has already been restricting a fine social and economic development of Dalian (Nakayama et al. 2010).

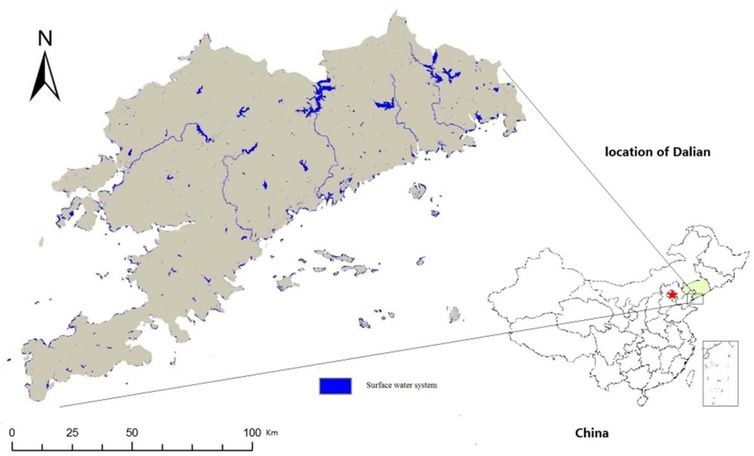


Figure 1. Location of study area

In order to analyze on manufacturing industrial CO_2 emissions and industrial water consumption of Dalian, we conducted the research to get the information into the forms of the following, (1) Official data from local official agent. In detail, the main socio-economic aspects of information were obtained from *Dalian City Statistical Yearbook* (from 2007 to 2011) and *Dalian City Twelfth Five Year Plan Report*; while water resource information came from Dalian Water Resources

© ASCE 2014

Bulletin (2001-2011). (2) As for carbon emission accounting section, estimates came from *IPCC Guidelines for National Greenhouse Gas Inventories and Energy Statistical Reporting System*. (3) To obtain more useful data, several field surveys and interviews have been conducted; all the data in our survey were collated and verified with official statistics for comparison.

Research framework

We chose the study time period from year 2006 to 2010, because it happens to correspond to the Dalian high-growth period of industrial economic with increasing carbon emission and water consumption. Meanwhile complete data of the above-scale industries for this period can be easily acquired, with unified industry classification standard based on the "national industry classification (GB_T_4754-2002)". According to this, the whole manufacturing sector of Dalian is divided into 29 industries, with industrial enterprises of main business income over 500 million CNY Yuan as statistical caliber. At the same time, we converted different energy types, such as coal, gas, et al, which were consumed during the producing process of manufacturing industry, into unified standard unit, which is standard coal, according to their different calorific values.

In order to eliminate the impact of price factors, each industrial output was measured in billion CNY Yuan in constant 2004 price.

All of these selected 29 industrial sectors could be grouped into three industrial types of labor-intensive, capital-intensive or technology-intensive industry using previous study (Huang S. 2011), according to their dependence on different production factors (labor, capital and technology). This classification could objectively reflect the real level of economic development of a region and the trend of industrial structure. G1, G2 and G3 are used to refer to labor-intensive, capital-intensive and technology-intensive industry respectively.

In order to identify factors that impact manufacturing industrial carbon emission and water consumption, two methods are usually used for decomposition of carbon emission: structural decomposition analysis (SDA) and index decomposition analysis (IDA). The former method is always used in input-output model, while the later method is more applicable for time series modeling. As one of the IDA method, the LMDI method was chosen in this research, because this method can not only eliminate residuals, but also save data of 0 value problems, with simple calculation process and intuitive decomposition results (Ang et al. 1998; Ang et al. 2005).The LMDI method has been widely used in carbon emission decomposition (Liu et al, 2007; Zhao et al,2010; Shao et al, 2014; Xu et al, 2014)and waste water emission decomposition (Geng, et al 2014), Unlike the traditional LMDI method which makes no account of industrial types, this research concerned difference between each industrial type, and aimed to explore optimization of urban manufacturing industrial structure to make most use of energy and water.

At first, carbon emission intensity and water consumption intensity were calculated for characteristic analysis. Furthermore, we used LMDI method to find four effect factors related to the carbon emission and water consumption during the period, which are economic growth, industrial structure, industrial proportion, energy/water intensity.

In detail, the economic growth effect reflects changes in the gross industrial output value from the base year (2006) to year *t*; Industrial structure effect reflects changes in the ratio of each industrial output of respective industrial type to overall GDP from the base year (2006) to year *t*; Industry proportion effect reflects changes in individual industry to corresponding industry type from the base year (2006) to year *t*; Emission intense effect reflects energy consumption per unit of GNP, from the base year (2006) to year *t*; Energy/water intensity index are used to characterize the input-output characteristics of the energy and water system, reflect the overall energy and water efficiency of economic activity. In addition, carbon emission factor effect reflects carbon emission coefficient of standard coal, which is constant during research period in practical applications, so the symbol is regard 0.

Accounting model of carbon emission and water consumption

Carbon emission

Total carbon emission can be denoted as followed equation,

$$CO2 = \sum_{ij} CO2_{ij} = \sum_{ij} Q \frac{Q_i}{Q} \frac{P_{ij}}{Q_i} \frac{E_{ij}}{P_{ij}} \frac{CO2_{ij}}{E_{ij}} = \sum_{ij} Q S_i I_{ij} e_{ij} C_{ij} \quad (1)$$

Where, $S_i = Q_i / Q$, $I_{ij} = P_{ij} / Q_i$, $e_{ij} = E_{ij} / P_{ij}$, $C_{ij} = C_{ij} / E_{ij}$, for further variables see table 1.

Table 1 Variables description of carbon emission account

Variable	Variable description	Unit
i	Manufacturing industrial type	None
j	Industry from certain type	None
CO2	Total carbon emission	tCO2
Q	Total economic output	CNY Yuan (about $0.1601)
Q_i	Economic output of type i	CNY Yuan (about $0.1601)
P_{ij}	Economic output of industry j from type i	CNY Yuan (about $0.1601)
E_{ij}	Comprehensive energy consumption of industry j from type i	Tce
$CO2_{ij}$	Carbon emission of industry j from type i	tCO_2

© ASCE 2014

S_i	Economic output in type i	Ratio
I_{ij}	Proportion of industry j from type i	Ratio
e_{ij}	Energy intensity of industry j from type i	tCO_2/CNY Yuan
C_{ij}	Carbon emission factor of industry j from type i	Ratio

CO_2 emissions changes from manufacturing industries can be decomposed into changes in its economic development, industrial structure changes, the proportion of industry, energy consumption intensity and carbon emission factor (This research discusses only the rate of change in carbon emissions of electricity excluding of hydropower and other energy).

So, decomposition model of each effect can be denoted as followed equation,

$$\Delta C_{gio} = \sum_{ij} \left(\frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \right) \ln(G^T / G^0)$$

$$\Delta C_{str} = \sum_{ij} \left(\frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \right) \ln(S_i^T / S_i^0)$$

$$\Delta C_{pro} = \sum_{ij} \left(\frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \right) \ln(I_{ij}^T / I_{ij}^0)$$

$$\Delta C_{int} = \sum_{ij} \left(\frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \right) \ln(e_{ij}^T / e_{ij}^0)$$

$$\Delta C_{ef} = 0$$

Where C_{ij}^T and C_{ij}^0 denote total carbon emissions in the base year (2006) and year *t*, respectively. Similarly, G^T, S_i^T, I_{ij}^T, e_{ij}^T and G^0, S_i^0, I_{ij}^0, e_{ij}^0 denote its meaning in the base year(2006) and year t. ΔC_{gio}, ΔC_{str}, ΔC_{pro}, ΔC_{int} and ΔC_{ef} denote different effect factors of economic growth, industrial structure, industrial proportion, energy intensity and carbon emission.

So, carbon emission changes from the base year to year T can be calculated using the following equation:

$$\Delta C_{tot} = C^T - C^0 = \Delta C_{gio} + \Delta C_{str} + \Delta C_{pro} + \Delta C_{int}$$

Water consumption

Total water consumption, like carbon emission, can also be denoted as followed

© ASCE 2014

equation below,

$$WATER=\sum_{ij} WATER_{ij}=\sum_{ij} Q\frac{Q_i}{Q}\frac{P_{ij}}{Q_i}\frac{W_{ij}}{P_{ij}}=\sum_{ij} QS_i I_{ij} d_{ij}$$

Where, $S_i = Q_i / Q$, $I_{ij} = P_{ij} / Q_i$, $d_{ij} = W_{ij} / P_{ij}$, for further variables see Table 2.

Table2 Variables description of water consumption account

Variable	Variable description	Unit
i	Manufacturing industrial type	None
j	Industry from certain type	None
W	Total water consumption	t
Q	Total economic output	CNY Yuan (about $0.1601)
Q_i	Economic output of type i	CNY Yuan (about $0.1601)
P_{ij}	Economic output of industry j from type i	CNY Yuan (about $0.1601)
W_{ij}	Water consumption of industry j from type i	t
S_i	Economic output share in type i	Ratio
I_{ij}	Proportion of industry j from type i	Ratio
d_{ij}	Water intensity of industry j from type i	t/CNY Yuan

Similarly, like above description of carbon emission decomposition, water consumption decomposition can be denoted by following equation.

$$\Delta W_{gio}=\sum_{ij}\left(\frac{W_{ij}^T-W_{ij}^0}{\ln W_{ij}^T-\ln W_{ij}^0}\right)\ln(G^T/G^0)$$

$$\Delta W_{str}=\sum_{ij}\left(\frac{W_{ij}^T-W_{ij}^0}{\ln W_{ij}^T-\ln W_{ij}^0}\right)\ln(S_i^T/S_i^0)$$

$$\Delta W_{pro}=\sum_{ij}\left(\frac{W_{ij}^T-W_{ij}^0}{\ln W_{ij}^T-\ln W_{ij}^0}\right)\ln(I_{ij}^T/I_{ij}^0)$$

$$\Delta W_{int}=\sum_{ij}\left(\frac{W_{ij}^T-W_{ij}^0}{\ln W_{ij}^T-\ln W_{ij}^0}\right)\ln(d_{ij}^T/d_{ij}^0)$$

Where W_{ij}^T and W_{ij}^0 denote total carbon emissions in the base year (2006) and year t, respectively. Similarly, G^T, S_i^T, I_{ij}^T, d_{ij}^T and G^0, S_i^0, I_{ij}^T d_{ij}^0 denote its meaning in the base year(2006) and year t. ΔW_{gio}, ΔW_{str}, ΔW_{pro} and ΔW_{int} denote different effect factors of economic growth, industrial structure, industrial proportion and water intensity.So, water consumption changes from the base year to year t can be calculated using the following equation:

$$\Delta W_{tot} = W^{T} - W^{0} = \Delta W_{gio} + \Delta W_{str} + \Delta W_{pro} + \Delta W_{int}$$

RESULTS

According to collected data, carbon intensity and water intensity can be calculated, and each illustrated as followed Figure 2 and Figure 3.

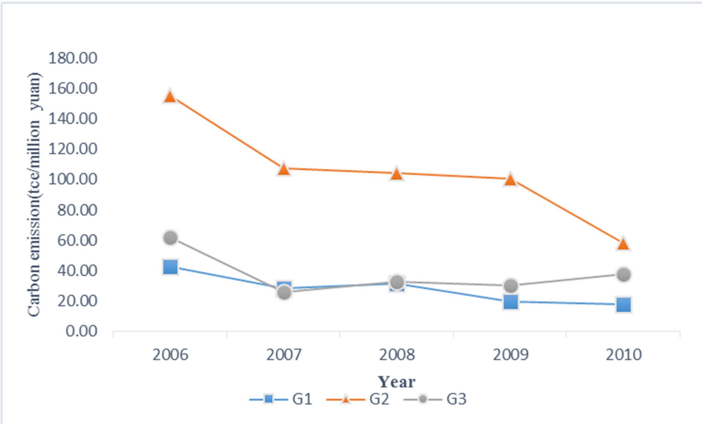


Figure 2. Manufacturing industrial carbon intensity during the period 2006–2010 in Dalian

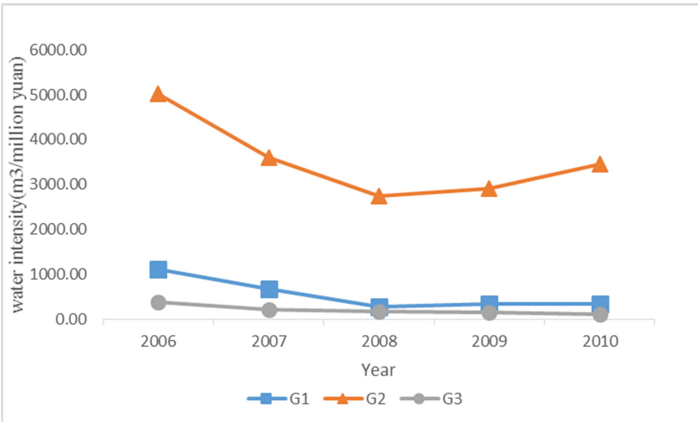


Figure 3. Manufacturing industrial water intensity during the period 2006–2010 in Dalian

As we can see, both of carbon emission and water intensity show obvious decrease from 2006 to 2008, while respectively stable from 2008-2009, and capital-intensive industries has the highest carbon emission and water intensity.

Furthermore, based on LMDI, effects that influence total manufacturing industrial carbon emission as well as water consumption in Dalian over the period 2006–2010 are analyzed as followed Figure 4 and Figure 5.

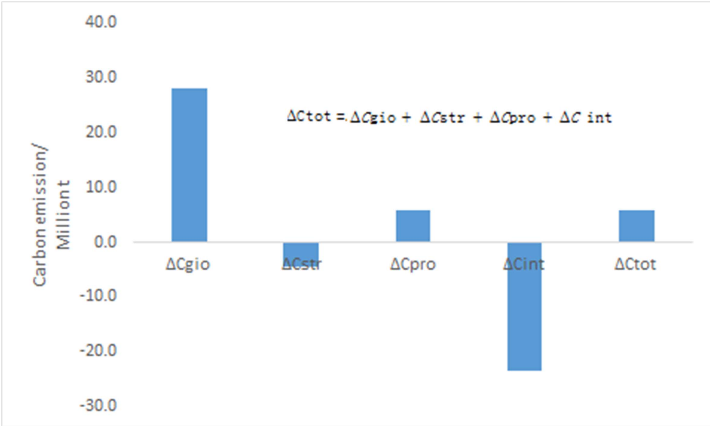


Figure 4. Accumulated effects of carbon emissions increment of total manufacturing industries in Dalian in 2010

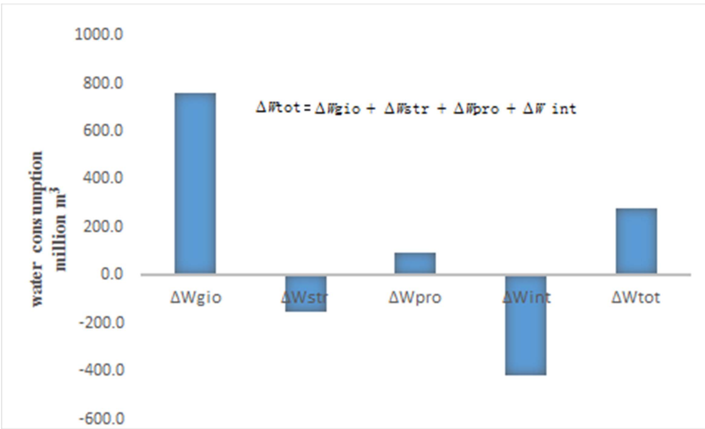


Figure 5.Accumulated effects of water consumption increment of total manufacturing industries in Dalian in 2010

We can see that economic grow is the dominant driving force of both carbon emission and water consumption, while industrial structure plays negative role in both of them.

In addition, effects that influence carbon emission as well as water consumption for each manufacturing industrial type in Dalian over the period 2006–2010 are analyzed as followed Figure 6 and Figure 7.

Capital-intensive industries plays a dominating role in carbon emissions and water consumption,.

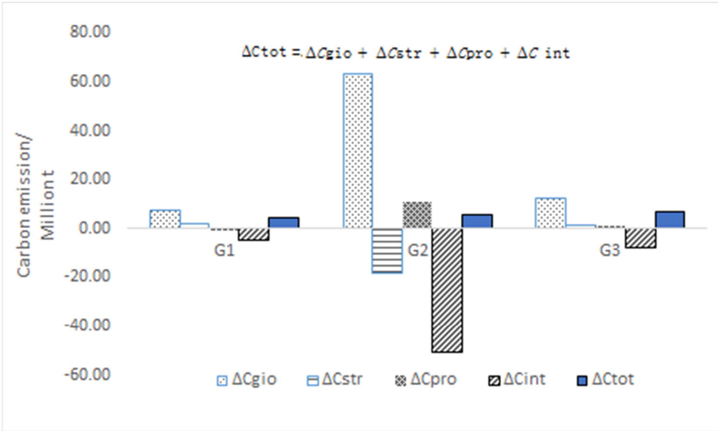


Figure 6. Accumulated effects of carbon emission increment of each manufacturing industrial type in Dalian in 2010

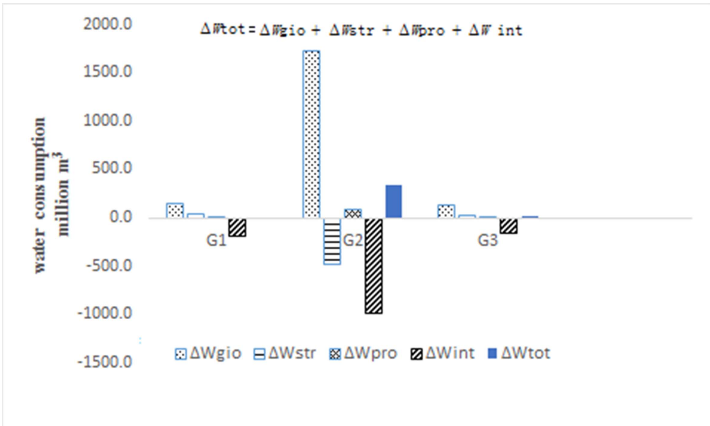


Figure 7. Accumulated effects of water consumption increment of each manufacturing industrial type in Dalian in 2010

CONCLUSION

The results showed that carbon emission and water consumption have similar growth patterns and impacts; economic growth is the most factors contribute to both of them, while intensity changes show vast decrease in carbon emission and water consumption. As for the industrial type structure, capital-intensive industries which had the highest carbon emission and water intensity played a dominating role in carbon emissions and water consumption, implementation of technology-oriented development as well as reducing the proportion of capital-intensive industries could not only effectively alleviate the pressure of the water supply, but also reduce carbon emission intensity.

© ASCE 2014

ACKNOWLEDGMENTS

This work was sponsored by the National Science & Technology Pillar Program, China (No.2012BAC05B02), the fund for Innovative Research Group of the National Natural Science Foundation of China (No. 51121003), and the National Natural Science Foundation of China (No. 41271105).

REFERECES

Ang B W, Zhang F Q, and Choi K H.(1998). "Factorizing changes in energy and environmental indicators through decomposition." *Energy*, 23(6): 489-495.

Ang B W. (2005). "The LMDI approach to decomposition analysis: a practical guide." *Energ. policy*, 33(7): 867-871.

Geng Y, Wang M, Sarkis J, Xue, B., Zhang, L., Fujita, T.， Yu, X., Ren, W., Zhang,L., and Dong, H.(2014). "Spatial-temporal patterns and driving factors for industrial wastewater emission in China". *J. Clean Prod.*, 76(2014):116-124

Gu A, Teng F, and Wang Y. (2014). "China energy-water nexus: Assessing the water-saving synergy effects of energy-saving policies during the eleventh Five-year Plan". *Energ. Convers. Manage*. 85, 630–637

Huang S., Tan Q. (2011). "An Empirical Analysis of the Innovation Efficiency of Manufacturing Industry." *Wuhan University of Technology (Social Science Edition).*, 24,27-33(in Chinese with English abstract)

Liu L C, Fan Y, Wu G, Wei, and Y. M.(2007). "Using LMDI method to analyze the change of China's industrial CO2 emissions from final fuel use: An empirical analysis." *Energ. Policy*, 35(11): 5892-5900.

Nakayama T, Sun Y, and Geng Y.(2010). "Simulation of water resource and its relation to urban activity in Dalian City, Northern China." *Global Planet. Change,* 73(3): 172-185.

Shao C, Guan Y, Wan Z, Guo, C., Chu, C., and Ju, M. (2014). "Performance and decomposition analyses of carbon emissions from industrial energy consumption in Tianjin, China." *J. Clean Prod*. 64, 590-601.

Ren S, Yin H, and Chen X H. (2014). "Using LMDI to analyze the decoupling of carbon dioxide emissions by China's manufacturing industry." *Environ. Dev.,*9, 61-75.

Wang W, Gao L, Liu P, and Hailud A. (2014). "Relationships between regional economic sectors and water use in a water-scarce area in China: A quantitative analysis." *J. Hydrol.*, 515, 180-190.

Xu S C, He Z X, Long R Y. (2014). "Factors that influence carbon emissions due to energy consumption in China: Decomposition analysis using LMDI." *Appl. Energ*. 127, 182-193.

Zhao M, Tan L, Zhang W, Ji, M., Liu, Y., and Yu, L. (2010). "Decomposing the influencing factors of industrial carbon emissions in Shanghai using the LMDI method." *Energy*, 35(6): 2505-2510.

© ASCE 2014

The Development of a Design and Modelling Framework for Grey Water Reuse in Tianjin, China

Jinhui Jeanne Huang[1] and Xiang Gao[1]

1Tianjin University / State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Weijin Road 92, Tianjin, P.R. China 300072; PH(86)22-2740-3676; email: huangj@tju.edu.cn

ABSTRACT：

Both water shortage and water pollution issues pose challenges for healthy living and economic growth. Tianjin, one of the biggest cities in North China, has experienced water shortage problem for many years, while the water pollution problem became more severe recently due to rapid urban development and fast growing economy. The recycling and reuse of grey water has brought people's attention. In this research, two categories of grey water, namely stormwater and effluents of wastewater treatment plant were studied. The issues of storage, further purification, distribution for reuse were addressed in this study.

Water recycling and reuse require integrated approaches for its collection, purification, storage and distribution. The recycling and reuse of grey water also need to meet certain water standards. It increases the challenge for the design, operation and management of the grey water recycling and reuse system. This research proposed a framework to employ coupled modeling tools SWMM + WASP + SUBWET to model the complex processes involved in the water recycling and reuse system. The coupled modeling framework addressed both the water quantity issue and water quality issue simultaneously.

This framework was applied to the aquatic ecosystem restoration project in Tianjin Airport Economic Area (TAEA), which includes a surface wetland for stormwater retention and purification as well as a series of subsurface wetlands for WTP effluents recycling, purification, redistribution and reuse.

© ASCE 2014

SWMM was used as main engine to simulate runoff, flow in stream and lake as well as the flow in the surface wetland. WASP was used to simulate the optimal hydraulic retention time in the surface water wetland in order to reach the surface water standard, while SUBWET was used to simulate the optimal hydraulic retention time in the subsurface wetland to meet the water quality requirement. The coupled modeling tools have successfully applied to the design and control of the constructed wetland including surface wetland and the subsurface wetlands. Seasonal variation of water quantity and quality are evaluated to ensure a sound design and a sustainable ecosystem.

Keyword: Grey Water Reuse, Wetland Design, SWMM, WASP, SUBWET

1 Introduction

The City of Tianjin is the fourth largest metropolis in China and the largest coastal city in northern China. Tianjin has a monsoon-influenced climate with cold, windy, very dry winters and hot, humid summers. The rainfall is very unevenly distributed during a year. More than 75% of the rain falls in only four months from June to September and the rainfall in the second half of July and the first half of August may account for more than 50% of the annual precipitation. The total annual renewable water resources per capita for Tianjin are 180 m^3. The number is less than 1/10 of the national average and is less than 1/36 of the world average. Water scarcity has become the bottleneck that limited the economic development of Tianjin. It is very important to seek an efficient strategy as well as practical technologies for the recycle and reuse of grey waters, e.g. stormwater and effluents of wastewater treatment plant (Li et al., 2004). The recycle and reuse of grey water can reduce the consumption of portable water as well as reduce the discharge of polluted waters. It shall resolve the water shortage fundamentally and may also have benefits in constructing a sustainable urban environment (Zhou et al., 2006).

The recycling and reuse of grey water also need to meet certain water quality standard. Since the first attempts to use constructed wetlands (CWs) for water quality improvements of untreated wastewater in the early 1950s, CWs are used successfully to treat domestic and industrial wastewater worldwide for secondary and tertiary treatment of domestic wastewater. The development and use of CWs for wastewater treatment has spread across the world (Haarstad et al., 2012; Kadlec and Wallace, 2009; Siracusa, 2006; Sundaravadivel and Vigneswaran, 2001; Vymazal, 2005). The use of CWs for the recycling and reuse of grey water has gained popularity in recent years to

© ASCE 2014

solve the water shortage issues in North China, for example, in Beijing and Tianjin. In this study, the constructed wetlands are also employed for the recycle and reuse of grey water in an area in Tianjin.

Water recycling and reuse requires integrated approaches for its collection, purification, storage and distribution. It increases the challenge for the design, operation and management of the grey water recycling and reuse system. This research proposed a framework to employ coupled modeling tools SWMM + WASP + SUBWET to model the complex processes involved in the water recycling and reuse system. The coupled modeling framework addressed both the water quantity issue and water quality issue simultaneously.

2 Materials and Methods

2.1 Study Area

The Tianjin Airport Economic Area (TAEA) is a typical urban watershed that is located on the east side of the old city of Tianjin with an area of 45 km^2 and is part of Binhai New Area (BHNA). As of the end of 2010, around 285 Fortune 500 companies had set up their headquarters/branches in BHNA that has become a new growth region in China. However, the rapid urban development also has worsened the fragile environment. Table 1 lists the average value for various water quality parameters measured between 2008 and 2010 by a bi-weekly monitoring program in the rivers and lakes of TAEA.

Table 1 Surface Water Quality in TAEA

Date	pH Level	COD mg/L	TN mg/L	NH3-N mg/L	TP mg/L	DO mg/L	BOD_5 mg/L
Average Monitoring Value	7.86	82.66	3.11	2.44	0.58	1.19	27.18
V class of National Standard	6~9	≤ 40	≤ 2	≤ 2	≤ 0.4	≥ 2	≤ 10

From the table above, we can see that all the values of pH, COD, TN, NH3-N, TP, DO and BOD level exceed the V Class requirements by the national surface water quality standards of China GB18918-2002. In order to sustain the economic development in TAEA and to improve its eco-aqua system, a master plan of eco-aqua system was developed. The strategies applied in the master plan include the following:

1) recognizing rainwater and effluents of wastewater treatment plant as a valuable resource,

2) using an ecosystem approach (the approach of using constructed wetlands for polishing grey water was adopted)

© ASCE 2014

3) implementing a hierarchy of wet weather flow practices starting with "at source", "conveyance", and then "end-of-pipe" solutions.

The four criteria including flood control criteria, water quality criteria, erosion control criteria and water balance criteria were all used in the Master Plan development. Monitoring program was also established for providing indications of the water quality improvement.

In order to resolve water resource problems, this study set four objectives as following:

1) Water Balance Criteria: based on the investigation of 56 years of rainfall records (Zhang, Huang and Lin, 2013), in Tianjin, storms with 24-hour volumes of 10 mm or less contribute about 50% of the total average annual rainfall volume and 50% rainfall events are less than 10 mm rainfall depth. Hence, the capture of 10-mm rainfall was set as the water balance criteria for this master plan development.

2) Water Quality Criteria:

a) Pollution reduction: improving the overall water quality to reach class IV national surface water quality standards

b) Providing sediment treatment efficiency of 80% and TP and TN treatment efficiency of 70% for stormwater runoff

3) Erosion Control Criteria: detention/retention of 25-mm 4-hr rainfall by releasing it in more than 24 hours

4) Flood Control Criteria: Control the peak flow rate of post-development to pre-development conditions

Based on the above criteria, an integrated water resource management strategy had been proposed for the Eco Aqua System Master Plan including water system reconnection, forming two water cycles, grey water reuse strategy, rainwater harvesting strategy, new flood control program, water monitoring program, etc.. A few constructed wetlands with different functionalities were proposed. They are

1) Wastewater treatment plant effluent polishing wetlands, which are subsurface wetlands to recycle and treat the effluents from waste water treatment plant, polishing the effluent to reach the IV class surface water standards in order to recharge the canals and lakes for water balance as well as meeting the pollution reduction objectives.

2) Wetland for polishing and connection, which are surface wetlands. The primary function for these wetlands is to connect the water system and to make the water moving in the system. The secondary function is to treat the water from canals and lakes so as to improve the water quality from V class standards to IV class standards. These wetlands also provide storages for flood control, erosion control as well as for water balance restoration.

3) River water polishing wetlands, which are subsurface wetland to treat the water from canals and lakes and to improve the water quality from being worse

than V class standards to IV class standards. It provides the function for meeting pollution reduction objectives.

4) Wetland Park, which consists of a few surface wetlands for further polishing the water from rivers and lakes. It provides the functions for flood control, erosion control, pollution reduction, sediment removal and water balance restoration.

5) Wetland Corridor, which consists of a few surface wetlands, grass swales and vegetated ditches. It provides the functions for flood control, erosion control, sediment removal as well as meeting water balance criteria.

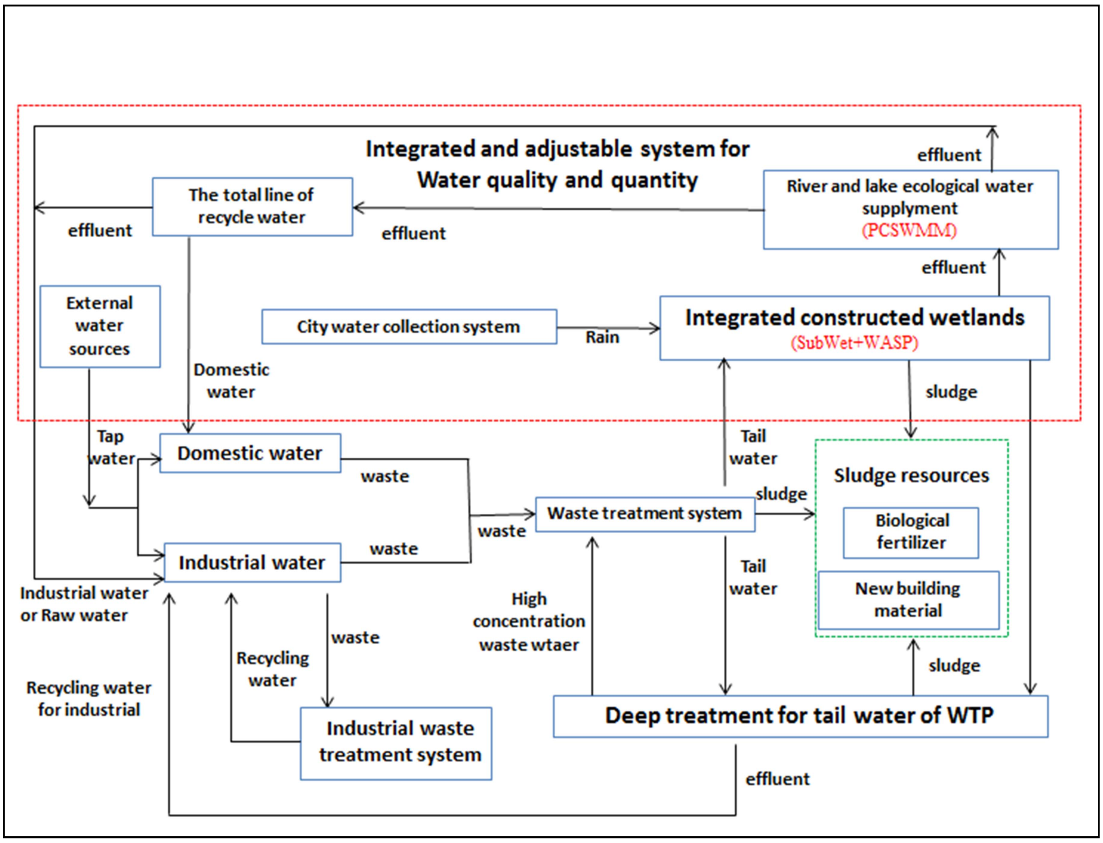


Figure 1. The schema of grey water reuse

Figure 1 shows the schema of grey water reuse strategies adopted by the Eco Aqua System Master Plan.

2.2 Modelling Frame Work

PCSWMM is a hydrological/hydraulic software and based on USEPA SWMM 5.0 as the core (SWMM is used to manage urban storm). This model can simulate the urban runoff and sewer discharge, inflow and outflow (withdraw) of the system.

SubWet was developed by UNEP-DTIE-IETC, a software program used in the design of horizontal flow constructed wetlands for water quality treatment.

© ASCE 2014

It was originally developed for warm climate applications and was successfully used as a design tool in 15 cases in Tanzania. A few years later, SubWet was upgraded for use within cold climates for both artificial and natural treatment wetlands. It can simulate the removal of BOD_5, nitrate nitrogen, ammonia nitrogen, organic nitrogen and TP. The model is distributed as free-ware by the United-Nations and can be found on the home web page for UNEP-IETC. This model was used in the modelling framework for the simulation of the constructed subsurface wetland for grey water recycle, mainly for treating and polishing the effluent of the wastewater treatment plant.

WASP stands for Water Quality Analysis Simulation Program, developed by the U.S. Environmental Protection Agency. It can simulate the water components of the physical, chemical and biological changes and mutual influences. This model was used in the modelling framework for the simulation of free surface wetland, which is used for treating the stormwater runoff.

The integrated modelling framework is based on PCSWMM + (SubWet and WASP), Subwet and WASP can simulate the influent and effluent concentration of the constructed wetlands as well as the hydraulic retention time (HRT) required for the recycled water reaching certain water standard or achieving certain treatment efficiency; PCSWMM can calculate and simulate the inflow and outflow (withdraw) of water for the entire system and performs as a core engine in the coupled modelling framework.

The above coupled modelling framework "PCSWMM+WASP+SUBWET" was used to assess the performance of the implementation of the proposed strategies in Eco Aqua System Master Plan for TAEA. It concludes the followings:

1) Flood Control: the new flood control program can enhance the utilization of existing and proposed storages in the system, and enhance the flood control capability
2) Water Quality Control: the proposed wetlands can provide sufficient sediment removal efficiency and the sufficient efficiency for removing TN and TP
3) Erosion Control: the Eco Aqua system master plan will provide sufficient storage for erosion control
4) Water balance: the proposed water recharge plan and the proposed wetland can provide more than sufficient capacity to restore the water balance as required.

2.3 Subwet---The simulation for the subsurface constructed wetlands

The first step of the modelling approach is to size the wetland and to set up the parameters for the biological, physical and chemical reaction processes occurring in the constructed wetland as well as to input the influent concentrations of DO, BOD_5, ammonia nitrogen, nitrate nitrogen, organic

© ASCE 2014

nitrogen and TP into the model.

In the simulation for the subsurface constructed wetland, the removal efficiency for pollutants can be evaluated by varying HRT and water temperature. According to the design sizes of the constructed wetlands, the influent volumes were specified under different HRT demonstrated as Table 2.

Table 2 The influent volume under different HRT

HRT (d)	1	2	3	4	5	6	7
Runoff (m^3/d)	400	200	133	100	80	67	57

Table 3 provides the designed criteria for the influent and effluent concentrations of the subsurface constructed wetlands.

Table 3 Influent, effluent, removal efficiency

Contents	Influent (mg/L)	Effluent (mg/L)	Removal efficiency (%)
BOD	10	6	40
Ammonium nitrogen	5	1.5	70
TN	15	1.5	81
TP	0.5	0.3	40

(1) BOD_5

The removal efficiency of BOD_5 was simulated by varying HRT between 1 and 7 days, while temperature was varied between -5 ^oC and 30 ^oC. The model results show that the removal efficiency of BOD is about 34%~74% under the above conditions. A 25% increases in removal efficiency of BOD was observed by increasing the temperature from -5 to 30 ^oC at the same level of HRT. A 20% increase in the removal efficiency of BOD was observed by increasing HRT from 1 to 7 days at the same temperature. However, the removal efficiency of BOD has no obvious increases under low temperature, even when the HRT was increased to more than 7 days.

(2) NH_3-N

The removal efficiency of NH_3-N is simulated with HRT between 1 and 7 days and temperature between -5 ^oC and 30 ^oC. The results show that the removal efficiency of NH_3-N is 5%~83% at the condition mentioned above. The removal efficiency of NH_3-N increases with the increase of temperature. The removal efficiency of NH_3-N increase from 5% to 51% by increasing the HRT from 1 to 7 days at temperature of -5 ^oC.

© ASCE 2014

(3) TN

The removal efficiency of TN is simulated under HRT from 1~7 days and temperature from -5 °C ~30 °C. The results show that the removal efficiency of TN is 9%~81% under that HRT is 1~7 day and temperature is -5~30 °C. And the degradation trend of TN is similar to the degradation trend of NH_3-N. So the nitrification has a positive correlation with the removal efficiency of TN. Meanwhile, carbon resource is essential to denitrification (XIAO et al., 2012). So we should take carbon resource into account for the wetlands design.

(4) The simulation results of TP

The removal efficiency of TP is simulated at the same condition as other parameters mentioned above . The results show that the removal efficiency of TP is about 25%~75% at HRT between 1 and 7 days.

2.4 WASP---The simulation for the free surface flow wetlands

The free surface constructed wetland was modeled by 14 cross-sections in WASP as shown in Figure 2. And the model was run for three scenarios, representing the low water lever of spring, the high water lever of summer, the middle water lever of autumn. The free surface wetland does not operate in Winter.

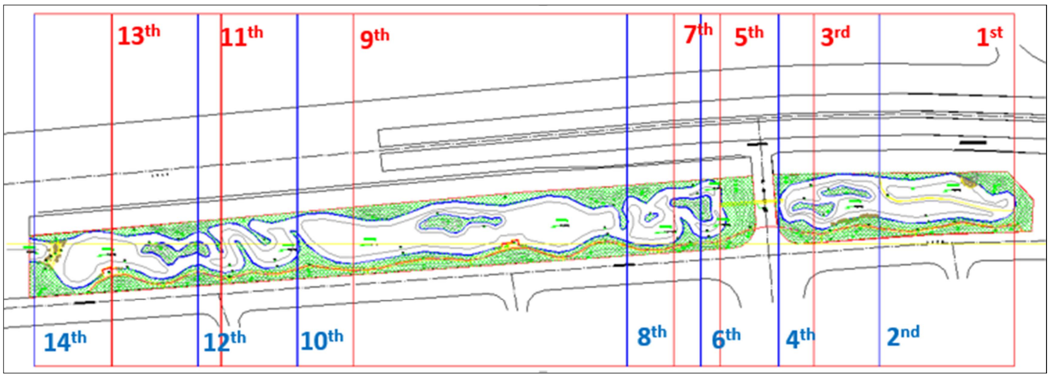


Figure 2. The monitoring sections of the constructed wetland

The Table 4 shows the concentration of the water quality parameters for the three scenarios.

Table 4 water quality for three scenarios

Time	Water level	DO	BOD	TN	TP
2010-3-17 00:00	Low level	6.2	14.6	5.34	0.624
2010-4-22 00:00	Low level	4.1	14.8	3.86	0.887
2010-5-22 00:00	Low level	6	20.1	2	0.864
2010-6-11 00:00	High level	5	20.1	1.2	0.067
2010-7-15 00:00	High level	6.05	14.7	4.26	1.14

© ASCE 2014

2010-8-12 00:00	High level	5.21	18.8	1.58	0.368
2010-9-16 00:00	Middle level	6.1	22.8	0.589	0.119
2010-10-14 00:00	Middle level	6.4	18.6	0.633	0.213
2010-11-18 00:00	Middle level	7	17.8	2.06	0.353

Table 5 shows the simulation results of BOD under low, middle and summer water level. And the simulation results can meet the design criteria set for the effluent of the free surface wetland as indicated in Table 3.

Table 5. The simulation results of BOD

Contents	Low level	Middle level	High level
BOD (influent) mg/L	21.5	23.5	35
BOD (effluent) mg/L	5	5.5	6

2.5 PCSWMM---The core engine of the framework

The area of the TAEA is about 23 km^2. It was divided into 604 sub-catchments in PCSWMM model. The PCSWMM model also simulated 612 collecting wells, 615 pipes, 4 rain water pumping stations, the cannel surrounding this area and the east and west lake systems. The hydrological model was run for the storm events for the return periods of 2 years, 5 years, 10 years and 15 years and the storm events recorded on July 24th, August 15th, November 1st in 2011. Table 6 lists the characteristics of these storm events.

Table 6 The simulation of working conditions

Working condition		Rainfall (mm)	Duration (hr)	Strongest rainfall intensity (mm/hr)
Return period (Year)	2	187	6	228
	5	237	6	289
	10	275	6	335
	15	297	6	363
The observed rainfall (Month. Day)	7.24	63	6	76
	8.15	67	12	39

© ASCE 2014

9.0 1	40	6	49

Table 7 shows that the retention storage capacity will increase by 40,800 m^3 by the designed constructed wetland. So more rainfall will be stored on site and runoff will be decreased by these constructed wetlands. The water can be gotten back to the hydrologic cycle by infiltration and evapotranspiration, which can reduce the salinity of groundwater and benefit the restoration of disrupted hydrological cycle..

Table 7 The volume of the regions

Working conditions		**Present situation**	**Present situation +Designed wetland**
Return period (Year)	2	59.52	74.08
	5	72.04	85.08
	10	92.8	96.89
	15	101.53	104.61
The measured rainfall (Month. Day)	7.2 4	32.84	33.73
	8.1 5	41.5	44.46
	9.0 1	28.03	32.11

3 Conclusions

The Eco Aqua System Master Plan was approved at the end of 2011. The implementation of the plan commenced in the beginning of 2012. A surface wetland with an area of 4 ha was constructed in 2012. By the construction of the surface wetland, the disconnected cannel was reconnected. Rich habitats were established with very diverse species including phytoplankton, emergent plants, trees, shrubs, birds, fishes etc. Runoff from surrounding areas was drained to this wetland, which provides the treatment capacity for sediment removal, TN and TP removal. The depression storage created by the wetland also provides the capacity for water balance restoration and flood control. A weekly water quality monitoring program was also established to assess the performance of the wetland. The monitoring results indicated that the objectives of the constructed wetland had met the terms of pollution reduction and sediment control.

References

Chung A K C, Wu Y, Tam N F Y, et al. Nitrogen and phosphate mass balance

© ASCE 2014

in a sub-surface flow constructed wetland for treating municipal wastewater [J]. Ecological Engineering, 2008, 32(8):81-89.

Harold L. L, Kristine H, et al. Anoxic treatment wetlands for denitrification [J]. 2010, 36(11): 1544- 1551.

LI Yu-Kun, LI Yu-Peng, LI Ming-Tao. On China's sewage treatment and sewage resources [J].Water Resources Protection, 2004(1): 3-5.

Langergraber G .The role of plant uptake on the removal of organic matter and nutrients in subsurface flow constructed wetlands: a simulation study [J].Water Science and Technology, 2005, 51(9):213-223.

Smith D, Li J, Banting D. A PCSWMM/GIS-based Water Balance Model for the Reesor Creek Water-shed [J].Atmospheric Research, 2005, 77(1-4):388-406.

State Environmental Protection Administration,GB 3838-2002 Environmental quality standard for surface water[S].Bei Jing: China Environmental Science Press 2002.

XIAO Lei, LIANG Xue, WU Zhen-Bin, et al. Research Advances of Adding Extra Carbon Sources to Denitrification for Constructed Wetlands [J]. Journal of Hydroecology, 2012, 33(1):139-143.

ZHOU Xi-Yang, LI Xiang-Xi, YU Ze-Qing. Rational utilization of city water resources several ways [J]. Subtropical Soil and Water Conservation, 2006, 18(3): 84-86.

© ASCE 2014

EHBR (Enhanced Hybrid Biofilm Reactor) application in the wastewater treatment of pharmaceutical R & D building

Linquan Sun [1], Ziyi Wang [1], Baoan Li[1]*
[1]Chemical Engineering Research Center, School of Chemical Engineering and Technology, Tianjin University, Tianjin 300072, PR China, PH +86-22-27403389; FAX +86-22-27403389; email: hgoff@tju.edu.cn

ABSTRACT

A study of the integrated EHBR system was conducted to investigate the performance of the system for treatment of pharmaceutical wastewater over 3 years. After 3 years of operation, the integrated EHBR system presented excellent ability of COD removal and notable impact resistance. The hydrolysis/acidification process could remove 7.2% of COD, 38.6% of TN and 9.5% of TP. And the removal efficiencies of COD, NH_4^+-N, TN, TP and SS in EHBR process were 85.5%, 96.2%， 71.1%, 72.5% and 81.1% respectively. After post-processingwith activated carbon adsorption, the effluent of integrated treatment EHBR system kept stable with COD below 200 mg/L，NH_4^+-N below 5 mg/L and TP below 3 mg/L.The integrated EHBR system could effectively and stably treat the high-loading mixed pharmaceutical wastewater from the high-tech pharmaceutical R&D building in Tianjincity of China, and the effluent quality could meet the wastewater discharge standard.

1. Introduction

Pharmaceutical wastewater is one of the refractory wastewater with high concentration and low biodegradability, which mainly includes four types: antibiotic industrial wastewater, waste water of synthetic drugs, waste water of proprietary Chinese medicines, and scouring water and washing water [1,2].Due to the complexity of pharmaceuticalwastewater composition, toxicity, deep chromaticity and high salt content, pharmaceutical wastewater has become one of the serious pollution sources[3]. The pharmaceutical wastewater must be treated tosatisfy the integrated wastewater discharge standard withspecific requirements of chemical oxygen demand (COD),ammonia nitrogen (NH_4^+-N), total nitrogen (TN), suspended solids(SS) and turbidity.However, it is always hard to satisfy discharge standards.

The enhancedhybrid biofilm reactor (EHBR) represents anew technology for wastewater treatment, in which gas permeablehollow fiber membranes are used for bubbleless oxygen transfer and also as the carrier of the biofilm [4-8]. With high oxygenmasstransfer efficiency and high specific biomass concentration, the specific microorganisms could be retained by the acclimation and accumulation forthe treatment of special wastewater [9-13].

The high-tech pharmaceutical R&D building in Tianjincity of Chinais a drugresearch and development base.ThepharmaceuticalR&D laboratories and pilot plants in the building produce about 10 tons of wastewater every day.The quality of the pharmaceutical wastewater is COD 2000-3500 mg/L, BOD_5/COD 0.20-0.39, TN 100-164 mg/L, NH_4^+-N 74-100 mg/L, TP 18-25 mg/LandSS280-350 mg/L. The wastewater must be treated to satisfy the Level 3 of Tianjin sewage discharge standard (COD 500 mg/L, BOD_5 300 mg/L, NH_4^+-N 35 mg/L, TP 3.0mg/L, SS 400mg/L).

Based on the feasible laboratory scale experiment, a pilot-scale integrated EHBR system, consisting of hydrolysis/acidification pretreatment, EHBR process and activated carbon adsorption post-processing, was designed to treat the high-loading mixed pharmaceutical wastewater. The integrated EHBR system was located in the basement of ahigh-tech pharmaceutical R&D building. Three innovative design were carried out in order to improve the performance of the EHBR process: (1) The scale-up membrane module was designedas cross flow curtain-like module and the fixed slots on the side wall of narrow flow channel reactor were used to fix the membranemodules, which could efficiently overcome feed flowshort-circuiting and improve the mass transfer; (2) Fine bubble aeration equipments were installed at the bottom of the EHBR reactor to improve the mixing of sludge and wastewater in the startup phase and supply the aided aeration at high COD loading condition; (3) The outlet gas from the membrane modules was collected into the air collection tank, and then used for the aided aeration.

2. Method

2.1. The configuration of integrated EHBR system

The schematic flow chart and assembly drawing of the integratedEHBR system are shown in Figure 1. The system consists of a hydrolysis/acidification pretreated pool, EHBR, net pool, andactivated carbon adsorption tank.

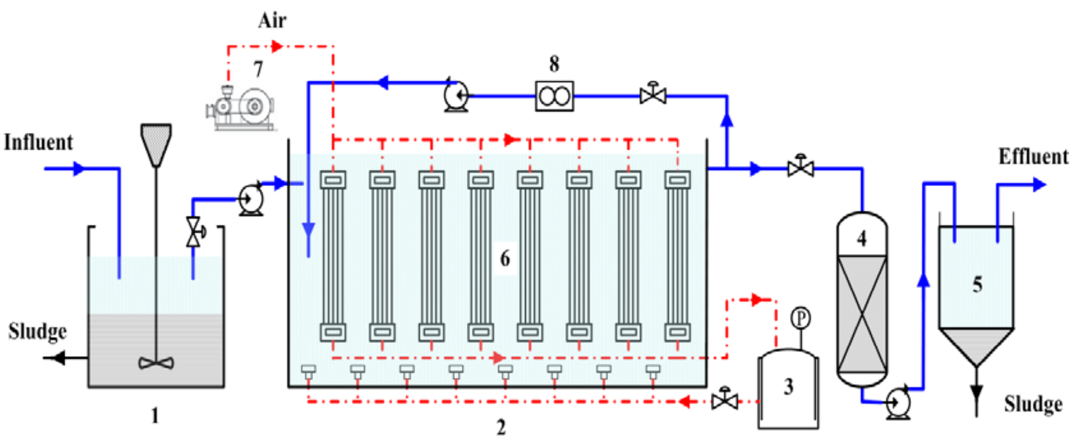


Figure1 Schematic flow chart of an integrated EHBR system.1- hydrolysis/acidification pool; 2- EHBR; 3- outlet air collection tank; 4- activity carbon absorption tank; 5- net pool; 6- membrane modules; 7- air compressor; 8- rotor flow meter

2.2. Analysis and monitoring

COD, turbidity and SS were measured in accordance withStandard Methods. Ammonium nitrogen (NH_4^+-N), nitrate andtotal nitrogen (TN) were measured according to spectrophotometry method using Multiparameter Bench Photometer for Laboratories (HI 83200, Hanna Instruments Inc., USA). Dissolved oxygen (DO) and

© ASCE 2014

pH were monitored using DO probe (JPBJ-608, ShanghaiPrecision & Scientific Instrument Co. Ltd., China) and pH probe (Delta320, Mettler Toledo, USA). The biofilm thickness was inferredfrom micromanipulator readings and visual observation.

3. Results and discussions

3.1. COD, NH_4^+-N and TN removal in EHBR process

Table 1 lists the amount of major pollutants in influent. Normal wastewater flow rate increased from 5 to $10m^3/d$ and the influent COD loading increased from 15 to 30kg/d. The systemwas monitored more than 36 months from the summer of 2010 tothe autumn of 2013.

Table 1 Main pollutant concentrations and loading rate in each phase

Phase	Time (month)	Flow rate (t/d)	COD (mg/L)	Total COD (g/d)	NH_4^+-N (mg/L)	TP (mg/L)	SS (mg/L)
Ⅰ	1-9	4.8	2878	13814	70.7	19.1	197.7
Ⅱ	10-22	6.6	2993	19753	70.9	19.4	217.1
Ⅲ	23-27	7.4	2369	17530	71.9	19.9	221
Ⅳ	28-36	10.2	2959	30181	75.6	20.4	230.6

As shown in Figure 2a, the COD removal in pharmaceutical wastewater by EHBR was maintained at high level during three-year operation period. The effluent COD was below 500mg/L. And the influent total COD increased from 13814g/d to 30181g/d during the whole operation period. Every time the increase of flow rate can have a great impact on EHBR system. Figure 2a also indicated that the impact generally lasted for one month. During this period the effluent COD was increased and the COD removal rate was fluctuated obviously. After that, the COD removal was gradually stabilizing and back to the removal level before the impact.

EHBR system had excellent removal efficiency on NH_4^+-N. As shown in Figure 2b, the NH_4^+-N removal was not influenced by the increase of influent, which illustrated that EHBR had excellent impact resistance.

The TP concentration in pharmaceutical wastewater was not high. C/P was about 100.The TP concentration was lower than the nutritive ratio needed by microbes.The TP removal was based on the demand of phosphorus in the biofilm update and cell synthesis process. The results showed that the TP concentration of effluentwas about 5mg/L, the TP removal was between 60% and 75%.

The effluent SS of EHBR process was around 50 mg/L, as shown in Figure 2d. EHBR process had excellent removal effect on SS in wastewater, the reason of which can be divided into two aspects:

(1) EHBRwas a kind of biological wastewater treatment with microbesattached growth. The large specific surface area of aerated membrane provided suitableconditions for the attached growth of microbes. Most of the microbesattached to the membrane surface, there was a few suspended microbes in the water. And the biofilm attached to the hollow fiber membrane firmly with little shedding phenomenon. The enrichment of zoogloea in biofilm provided

excellent settling ability for biofilm. Even though the shedding phenomenon could occur, the biofilm would settle at the bottom of the reactor. Low circulation velocity and overflow effluent were employed to decrease the effluent SS

(2) The hollow fiber membranes and biofilm had interception effect on microbes and SS in wastewater. The released extracellular polymeric substances (EPS) by biofilm had adhesion effect on SS. The effluent SS concentration was decreased.

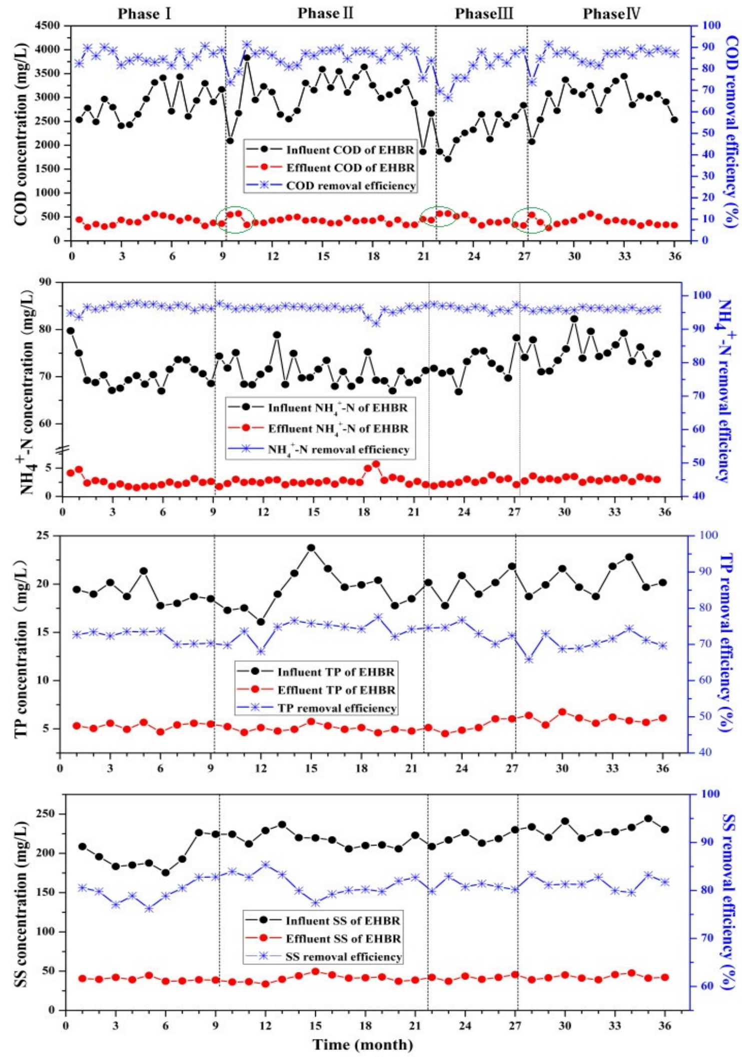


Figure2COD (a), NH4+-N (b), TP (c) and SS (d) removal ofEHBRprocess

3.2. Effectiveness analysis of processes in EHBR system

The contributions of different stages of the integrated EHBR system to remove the main contaminants in pharmaceutical wastewaterwere listed in Table 2.

© ASCE 2014

Table 2 Analysis of each process performance in the integrated EHBR system

Process	Item	COD	NH_4^+-N	TN	TP	SS
Hydrolysis/ Acidification	Influent average value（mg/L）	3122.9	76.85	143.64	21.70	296.57
	Effluent average value（mg/L）	2896.5	72.2	88.2	19.64	216.2
	Removal rate（%）	7.2	6.1	38.6	9.5	27.1
	Contribution value（%）	7.6	6.2	44.7	10.6	27.4
EHBR	Influent average value（mg/L）	2896.5	72.2	88.2	19.64	216.2
	Effluent average value（mg/L）	417.4	2.73	24.9	5.4	41
	Removal rate（%）	85.5	96.2	71.7	72.5	81.1
	Contribution value（%）	83.8	92.6	51.1	73.1	59.8
Activated carbon adsorption	Influent average value（mg/L）	417.4	2.73	24.9	5.4	41
	Effluent average value（mg/L）	166.1	1.8	19.8	2.2	3.9
	Removal rate（%）	60.2	32.4	20.3	58.8	90.3
	Contribution value（%）	8.4	1.2	4.1	16.2	12.6
Final effluent	（mg/L）	166.1	1.8	19.8	2.2	3.9
Total removal rate	（%）	94.6	97.5	86.1	89.7	98.6

Hydrolysis acidification was the first stage of anaerobic biological reaction, refractory complex organics were degraded into low grade organic acids and alcohols by acid-producing bacteria in this stage, thereby improving biodegradability of the wastewater. And the high organic loads can be withstood and the pHof wastewater can be decreased by hydrolysis acidification. In addition, the denitrification and influent SS degradation were occurred in hydrolysis acidification, so the TN removal reached up to38.6%. Activated carbon adsorption was adopted in post-treatment to ensure the effluent quality. Two Activated carbon adsorption tanks were placed in

© ASCE 2014

parallel and usedalternatively,so that once the adsorption of activated carbon in one tank reached saturation, the other one can be used.The loading rateof activated carbon post-treatment process was low and the removal of the main pollutantswas limited.However, this processeffectively improved the quality and decreased the SS and TP concentration of effluent. EHBR process was the main removal unit of COD, NH_4^+-N , TN, TP andSS, the removal rate were85.5%, 96.2%，71.1%, 72.5% and 81.1% respectively.

4. Conclusions

A pilot-scale integrated EHBR system was built and operated totreat the mixed pharmaceutical wastewater. After 3 years of operation,the integrated EHBR system presented the excellent ability of COD removal and notable impact resistance. The system showed good stability, during normal operation period, unattended operationwasbasically realized. The effluent quality of integrated EHBRsystem could meet the integrated wastewater discharge standard.These results indicated that integrated EHBR system is anefficient technology for the treatment of high loading rate andcomplex wastewater.

REFERENCES

Enick, O. V., and Moore, M. M. (2007). "Assessing the assessments: pharmaceuticals in the environment." *Environ. Impact Assess. Rev.*, 27: 707-729

Oktem, Y. A., Ince, O., Sallis, P., Donnellyc, T., and Inced, B. K. (2007). "Anaerobic treatment of a chemical synthesis-based pharmaceutical wastewater in a hybrid upflow anaerobic sludge blanket reactor." *Bioresour. Technol.*, 99: 1089-1096

Carballa, M., Omil, F., Lema, J. M., Llompart, M., Garcia-Jares, C., Rodriguez, I., Gomez, M., and Ternes, T. (2004). "Behavior of pharmaceuticals, cosmetics and hormones in asewage treatment plant." *Water Res.*, 38: 2918-2926.

Casey, E., Glennon, B., and Hamer, G. (1999). "Review of membrane aerated biofilm reactors." *Resour. Conserv. Recycl.,* 27: 203-215.

LaPara, T. M., Cole, A. C., Shanahan, J. W., and Semmens, M. J. (2006). "The effects of organic carbon, ammoniacal-nitrogen, and oxygen partial pressure on the stratification of membrane-aerated biofilms." *J. Ind. Microbiol. Biotechnol.*, 33: 315-323.

Syron, E., and Casey, E. (2008). "Membrane-aerated biofilms for high rate biotreatment: performance appraisal engineering principles, scale-up, and development requirements." *Environ. Sci. Technol*,. 421833-1844.

Shanahan, J. W., and Semmens, M. J. (2004). "Multipopulation model of membrane-aerated biofilms." *Environ. Sci. Technol.*, 383176-3183.

Cole, A., Semmens, M., and LaPara, T. (2004). "Stratification of activity and bacterial community structure in biofilms grown on membranes transferring oxygen." *Appl.Environ. Microbiol.*, 70: 1982-1989.

Brindle, K., Stephenson, T., and Semmens, M. J. (1998). "Nitrification and oxygen utilizationin a membrane aeration bioreactor." *J. Membr. Sci.*, 144: 197-209.

Yamagiwa, K., Yoshida, M., Ito, A., and Ohkawa, A. (1998). "A new oxygen supply method for simultaneous organic carbon removal and nitrification by

© ASCE 2014

aone-stage biofilm process." *Water Sci. Technol.*, 37117-124.

Terada, A., Yamamoto, T., Hibiya, K. Tsuneda, S. and Hirata, A. (2004). "Enhancement of biofilm formation onto surface-modified hollow-fiber membranes and its application to membrane-aerated biofilm reactor." *Water Sci. Technol.*, 49263-268.

Yamagiwa, K., Abe, M., Shibai, M., Yoshida, M., Ohkawa, A., and Furusawsa, M. (2004). "Nitrification performance of membrane-attached nitrifying biofilm." *J. Chem. Eng. Jpn.*, 37: 1423-1426.

Satoh, H., Ono, H., Rulin, B., Kamo, J., Okabe, S., and Fukushi, K. (2004). "Macroscale and microscale analyses of nitrification and denitrification in biofilm sattached on membrane aerated biofilm reactors." *Water Res.*, 38: 1633-1641.

© ASCE 2014

INDICATOR SYSTEM PERSPECTIVES ON THE DEVELOPMENT OF ECO-CITIES IN CONTEMPORARY CHINA[1]

Chen Tian[1], Wang Xiaojun[2], Wang Liangliang[3]

[1] Chen Tian, Department of Urban Planning, School Of Architecture, Tianjin University, Professor. Director of the Institute of Urban Space and Urban Design. Doctoral Advisor. E-mail: chentiantju@gmail.com
[2] Wang Xiaojun, Department of Urban Planning, School Of Architecture, Tianjin University, Doctoral Students. E-mail: xj83mail@gmail.com
[3] Wang Liangliang, School of Architecture and Environment, The National University of Singapore, Doctoral Students. E-mail: wangliangliang@nus.edu.sg

ABSTRACT
The rapid development of China's eco-cities is in accordance with all of the different stages of the indicator system support. This paper will provide a breakdown of the different stages of eco-city development and it will explain the seven representative indicator systems. This will be done through comparative analysis of the contents, different changes in resources, the environment and the change in economic and social objectives.
This will reflect the future trends and the characteristics of China's eco city development.

KEYWORDS: Eco-City, Indicator System, Comparative Study

1 Eco-city Development Stages in China

1.1 Definition of an Eco-city

China is one of the most active countries in terms of the construction of eco-cities in the world. However, this rapid economic growth is accompanied by the negative effects on the urban environment from industrialization and urbanization. In the 1970's China participated in the UNESCO "Man and Biosphere" program. Many scholars focused on the research of Eco-cities. From their professional points of view, they put forward different definitions of Eco-cities. Experienced environmentalists transferred theory from urban ecological protection into practice in the development of eco-town construction.

---

[1] Supported by the Research on High-density Space Environment Efficiency Optimizing of Town Cluster (Grant No. 2012BAJ15B03), Sub-project of the Key Projects in the National Science & Technology Pillar Program during the Twelfth Five-year Plan Period.

© ASCE 2014

Research targets learning from the theory and practice of other countries' experiences in developing eco cities, in order to find a suitable way to construct eco-towns. These eco towns must also be made in accordance with the characteristics of Chinese urban development.

With the combination of these findings it is thought that the current eco-cities in China are based on the sustainable development of resources, environment, economy, society, and the use of the principles of ecology. Resource-saving and environmentally-friendly settlements with sustained economies are also important for human nature and eco cities to benefit from each other. [1]

1.2 Division of Eco-city Development Stages

After nearly 30 years of construction and research, Chinese eco-city development is generally still in its early stages. For the theoretical and practical aspects, it can be divided into several stages which can show the development trends. The division of eco city development stages, follow four points: (a) the process from theoretical study to practice study; (b) the establishment and consideration assessment of eco-city indicator systems as one of the important parts in eco-city planning. Including the Indicator system's self-perfection on behalf of the eco-city construction progress; (c) rapid increase of eco-city projects in China's provinces; (d) the evaluation criteria and regulations released by national agencies.

China's eco-city construction and development can be divided into three stages: The Exploration trial stage before 2007; The main bulk of the construction stage from 2007 to 2011 and The Rational reflection stage after 2011 (Figure 1).

Before 2007, China was aware of the deterioration of urban environmental issues. The main concern was to improve the urban environment and to reduce carbon emissions. In 1986, Yichun City in Jiangxi Province, was first to propose the construction of eco-city construction goals. In 2004, the Ministry of Construction issued a paper named 'National Ecological Garden City Standards (Provisional)'. In 2005, Shanghai tried to build a new town with zero carbon emissions in Dongtan. During the exploration stage, there were less numbers of eco-city constructions.

Starting in 2007, through the cooperation of provinces and the provincial ministry of collaboration, some international eco-city projects were signed throughout the country. This was to accelerate the scale and development of eco-city construction, including the national ecological demonstration projects in: Sino-Singapore Tianjin Eco-City and Tangshan Bay Caofeidian Eco-City.

As well as the 'Eco-county, Eco-city and Eco-province construction indicator trials issued by the Ministry of Environment in China. The local eco-cities also established their own indicator systems in planning, design and construction in line with the city's respective urban characteristics. In 2011, in order to overcome the defects during the construction of eco-cities and in order to make sound progress, the Development and Reform Commissions of China promoted pilot projects of low-carbon provinces and cities. The Ministry of Housing and Urban-Rural Development launched a project named 'Low Carbon Ecological Pilot Town Declarations and Management Interim Measures' this was to define the threshold of low-carbon eco-city standards.

Social media and academics have started to rethink the construction of ecological cities. Although there are many eco-cities built quickly, the overall trend is driving the development of urban construction, planning, design and related studies toward the direction of ecological civilization and comfortable living.

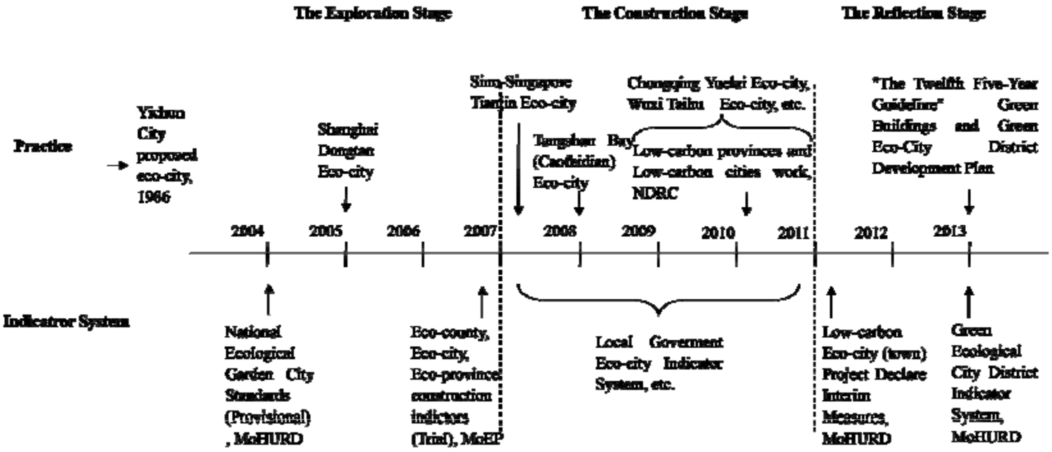


Figure 1. Eco-city Development Stages

2 Elements of Eco-city Indicator Systems

2.1 General Characteristics of an Indicator System

In different stages of development, eco-city indicator systems are used as criteria for the evaluation standard to determine whether the city meets the principles of a low-carbon eco-city or not. The collaboration of the index system is mainly between national ministries, research institutions, eco-city management committees or universities and consulting companies. Collaboration among the foreign institutions has resulted in the construction of international eco-cities. Most indicator systems have three-layer structures: the target layer, the guide layer and the indicator layer. All of these reflect the development conditions of resources, the environment, the economy, and social dimensions.

According to different time periods, seven indicator systems are selected to summarize and analyze the different relationships between compiling units and the development trends of indicators (Table 1).[2]

Table 1. Indicator System Overview

	Indicator system	Authorities	Year of Establishment	Number of indicators	Features
1	National Ecological Garden City Standards (Provisional)	Ministry of Construction	2004	19	First batch : 12 cities
2	Eco-county, Eco-city, Eco-province construction indictors (Trial)	Ministry of Environment Protection	2007	22	To August 2008 six cities of two provinces entitled to 'National Eco-city'.

3	Sino-Singapore Tianjin Eco-city Indicator System	Eco-City Administrative Committee, Tsinghua University	2008	26	22 controlling indicators, 4 guiding indicators
4	Tangshan Bay (Caofeidian) Eco-city Construction Indicator System	Eco-City Administrative Committee, Swedish SWECO Company	2009	141	
5	Wuxi Taihu Newcity National Low-carbon Eco-city, Demonstration Area Planning Indicator System	Wuxi City Planning and Design Institute, Arup Engineering Consulting (Shanghai) Co., Ltd.	2010	62	
6	Chongqing Green Low-carbon Eco-city Evaluation Indicator System (Trial)	Urban and Rural Construction Committee	2012	59	
7	Low-carbon Eco-city Indicator System	Chinese Society for UrbanStudies，CSUS	2012	30	

Initially, the authority to formulate indicator systems belonged to national ministries and other relevant departments. When the eco-city is widely recognized, the authorities are changed to local eco-city management committees and consulting institutions. [3]At the same time, with their own practical experience; research institutions also set out indicator systems based on survey. The indicator systems formulated by the national department are applied in a broader range to judge whether the urban ecological environment has its own unique features. Local eco-city management committees put more emphasis on respective urban characteristics and the eco-city indicator system's threshold at different development stages (Figure 2).

© ASCE 2014

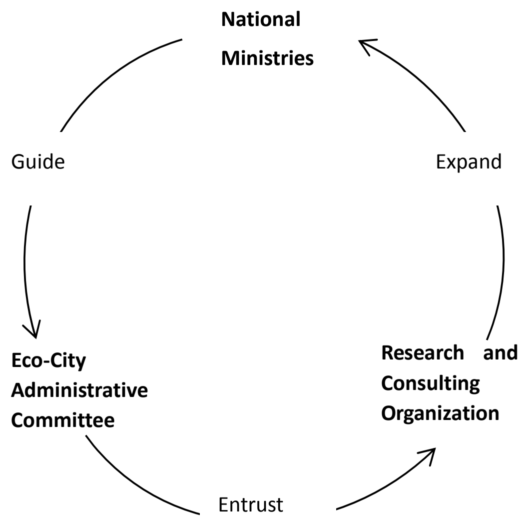


Figure 2. The Indicator System of Compiling Units

In the different stages of development, the numbers of eco-city indicator systems are increasing. Recently, the number of indicators has been controlled by some targets. The increasing numbers of indicators illustrates the incremental considerations of eco-cities. However, complicated indicator systems are not conducive in terms of actual use and management. Indicators of future trends will put more emphasis on the actual control and guiding role during construction process.

2.2 Key Elements of Indicator Systems

The most critical element of indicator systems might be the indicators. In different dimensions, indicators could be classified into different preparation purposes. Indicator systems mean that dimensional elements can be measured by number or ratio. Dimensions usually associate with multiple indicators to deepen data hierarchy. Indicator systems track data through a single indicator and reflect macroeconomic conditions through gathering multiple indicators. Therefore, different classification methods reflect different objectives of evaluation systems and compiling units. [4]

Indicators of China's eco-city indicator system could be generally classified into five categories: resource, environment, economy, society, and characteristics. The first four categories are the basic core of eco-city's sustainable development. The characteristics of indicators reflect different compiling purposes (Table 2 & Figure 3). For example, the eco-city indicator system of Yangzhou, consists of 3 aggregated indicators, development status, development dynamics, and development strength[5][6].

© ASCE 2014

Table 2. Main Indicators of Indicator System

	Indicator system	Indicators Group				
		Resources	Environment	Economy	Society	characteristics
1	National Ecological Garden City Standards (Provisional)	-	B1、B2、B3、B4、B5、B6、B7	-	D3	E15、E16、E17
2	Eco-county, Eco-city, Eco-province construction indictors (Trial)	A2	B1、B2、B4、B8	C1	D3	E13、E14
3	Sino-Singapore Tianjin Eco-city Indicator System	A1、A2、A3、A4、A5	B1、B2、B3、B4、B5、B6	C1、C2	D1、D2、D4	E12
4	Tangshan Bay (Caofeidian) Eco-city Construction Indicator System	A1、A4、A7	B2、B3、B4、B5、B6、B8、B10	C1、C4	D2、D4、D5	E9、E10、E11
5	Wuxi Taihu Newcity National Low-carbon Eco-city Demonstration Area Planning Indicator System	A1、A2、A3、A4、A5、A6、A7	B1、B2、B3、B4、B5、B6、B7、B8、B9、B10	C1、C2、C3、C4	D1、D2、D3、D4、D5	E4
6	Chongqing Green Low-carbon Eco-city Evaluation Indicator System (Trial)	A1、A4、A5、A6、A7	B1、B2、B3、B4、B5、B6、B7、B8、B9	C2、C3、C4	D2	E1、E2
7	Low-carbon Eco-city Indicator System	A1、A2、A3、A4	B1、B2、B3、B4、B5、B6	C1、C2	D1、D2、D3、D4、D5	E5、E6、E7、E8、E13

In table 2, letters and figures represent:

Resources	Environment	Economy	Society	Features
A1. (Recycled water / non-conventional water) utilization rate A2. Carbon emissions per unit of GDP / solid waste emissions A3. (Unit of GDP / per capita) energy / water consumption A4. Proportion of non-fossil energy / proportion of renewable energy A5. Proportion of green	B1. Air quality the number of days / PM2.5 standard daily average concentration of the number of days B2. Water quality compliance rate / Water Quality B3. (Garbage / waste) harmless rate (living / industrial) B4. Noise standard coverage B5. Services public	C1. (R&D / high-tech industries) expenditure to GDP C2. Job-Housing Balance index C3. Proportion of green building materials used C4. Proportion of industrialization of residential	D1. Proportion of affordable housing D2. Proportion of green travel D3. Community satisfaction D4. Accessibility D5. Accessibility of public facilities	E1. Industry intensity of investment E2. Construction Management (Information) sophistication E3. Slow traffic road network density E4. Green communities, green schools create rate E5. Capita construction land / building density E6. Commuting time

© ASCE 2014

building A6. Underground space utilization A7. Compact layout (proportion of mixed-use neighborhood function)	facilities 500m radius of coverage (parkland / living facilities, etc.) B6. Biodiversity / number of native plants B7. Heat island intensity B8. Per capita public green B9. Pedestrian zone speed B10. Residential area sunshine compliance			E7. Levels of urban disaster prevention E8. Housing prices to income ratio E9. Bicycle-friendly environment E10. Visibility of water and green / Historic Buildings E11. Coastal environmental Defence E12. Net loss of natural wetlands E13. Annual income of farmers / urban income / Gini coefficient E14. Forest coverage E15. Permeable land area ratio E16. Thousand people who have beds E17. Primary and secondary roads the average speed

Indicator systems own respective indicator classification methods. This article takes one kind of classification approach. For example, Wuxi Taihu New city planning indicator system, places ‘Carbon Emissions per Unit of GDP’ into the category of ‘Social Harmony’. While CSUS's indicator system, places it into the category of ‘Resource Saving’. Because the main purpose of this article is to evaluate urban carbon emissions, ‘Carbon Emissions per Unit of GDP’ is classified under the category of ‘resource conservation’. According to the above statistical tables, the key elements of the present Chinese indicator system can be shown clearly in the following figure (Figure 3).

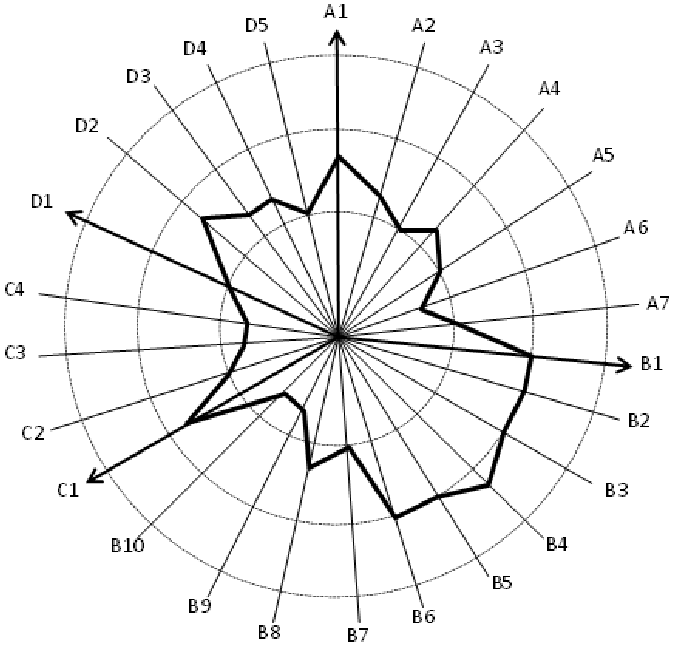


Figure 3. The Frequency of Indicators

Among all of the above indicator systems, the indicators belong to the 'environment category' which occupies a predominant proportion, which is 40%. Following the indicator regarding resources, the ratio reaches to 27%. Economics and social indicators, relatively own few ratios, but it can be seen in the growing trend of both categories in indicator systems.

The following indicators are the most important elements in the 'resource category': the use of water, renewable energy, disposal of gas, waste water and solid waste per unit of GDP. Green building design and efficient use of urban space, air, water, and noise standards are also included. As well as waste disposal per capita, green space, thermal, wind, lighting environment and biodiversity situation.

In some indicator systems, such as Sino-Singapore Tianjin Eco-City and Wuxi Taihu New city, the economic and social indicators are increasingly important. This means that when the environment and resource indicators meet the standards, the economic and social indicators will become the next consideration.[7] Meanwhile, the tertiary industry should be the main sector in eco-cities, which is mainly focusing on high-tech and pollution-free cities. In the residential aspect, elements such as the job-housing balance, green residence, affordable housing, efficiency in the use of public facilities and different social groups should be paid more attention to.

© ASCE 2014

3 Indicator System is used to Measure the Development of Eco-city

3.1 Eco-city Indicators under Resource Conservation

The key indicators for resource conservation are listed in the following table (Table 3). Utilization of non-conventional water resources and renewable energy resources are the most important core indicators of China's eco-city. The indicators related to energy consumption and carbon emissions per unit of GDP also get more attention. [8]In order to facilitate comparison and reduce duplication, this research selects a wider range of indicators in the table as presented;

Table 3. Key Values of Resource Categories Indicators

Eco-city / Indicators	National Ecological Garden City Standards (Provisional)	Eco-county, Eco-city, Eco-province construction indictors (Trial)	Sino-Singapore Tianjin Eco-city Indicator System	Tangshan Bay (Caofeidian) Eco-city Construction Indicator System	Wuxi Taihu Newcity National Low-carbon Eco-city Demonstration Area Planning Indicator System	Chongqing Green Low-carbon Eco-city Evaluation Indicator System (Trial)	Low-carbon Eco-city Indicator System, CSUS
Non-conventional water use efficiency (%)	-	-	≥50	＜30	≥40	≥20	2015≥ 15, 2020 ≥ 20
Carbon emissions per unit of GDP (tons / million)	-	-	≤1.5	-	≤0.9	-	2015=2.13, 2020= 1.67
Unit GDP energy consumption (tons standard coal / million)	-	≤0.9	-	-	≤0.3	-	2015≤0.87, 2020≤0.77
Proportion of renewable energy (%)	-	-	≥20	-	≥8	≥5	2015≥15, 2020≥20
New Project Green Building percentage (%)	-	-	100	-	-	100	100
Underground Space Development	-	-	-	-	≥80	Encourage the development	-

degree (%)							
Mixed-use neighborhood percentage (%)	-	-	-	40-50	≥50	-	-
Remark			Protection of natural wetlands	Sea water desalination	100% Create green communities, green schools	Implementation of low-carbon operation and management mechanism, the implementation of carbon measurement	Construction land per capita in 2020 ≤ 80 sq.m / person

Take the indicator of non-conventional water use for instance. The use of non-conventional water is an indicator of resource conservation. By comparing different indicators, the utilization of non-traditional water in areas of water sparsity is not less than 40%, and in the other areas is not less than 20%. Not only the use of non-conventional water resources, but also the use of water-saving appliances might effectively conserve water resources. In terms of energy consumption, according to the "Renewable Energy Law", the plan of renewable energy is one essential part of the city planning. [9] In material use and land use aspects, it is encouraged for all new buildings to achieve green building star standards. Meanwhile, through the utilization of underground space and increasing the building density the land resources may be largely saved.

3.2 Eco-city Indicators under Environmentally Friendly

Generally, indicators about the environment might be one of the most widely covered aspects in the system and have a large number of elements, which clearly shows that improving the urban environment is quite important for the eco-city construction. These indicators include air quality, water environment, noise control and waste disposal. As well as public green space and service facilities coverage.

For example, the indicator ‘good air quality days’ listed in the table below, is given different values from the various factors in different eco-cities. Most eco-cities attained Grade Ⅱ national standards for air quality. The Sino-Singapore Tianjin Eco-city proposed that the days that they reach Grade Ⅰ air quality will not be less than 155. (Table 4) Regarding water environment indicator aspects, all the eco-cities' compliance rates are 100%. But there are differences between different cities for water quality requirements. Most eco-cities should assure compliance with the national standards for water environment quality.

Table 4. Key Values of Environment Categories Indicators

Eco-city / Indicators	National Ecological Garden City Standards (Provisional)	Eco-county, Eco-city, Eco-province construction indictors (Trial)	Sino-Singapore Tianjin Eco-city Indicator System	Tangshan Bay (Caofeidian) Eco-city Construction Indicator System	Wuxi Taihu Newcity National Low-carbon Eco-city Demonstration Area Planning Indicator System	Chongqing Green Low-carbon Eco-city Evaluation Indicator System (Trial)	Low-carbon Eco-city Indicator System, CSUS
Air quality days	≥300	-	≥310	-	≥350	≥290	≥320
Garbage harmless treatment rate (%)	≥90	≥90	100	100	100, recycling rate ≥ 95	100, recycling rate ≥ 50	100, recycling rate ≥ 80
Water Environment compliance rate (%)	100	Cities without inferior class Ⅴ water body	Reach Grade Ⅳ water quality	100	Not less than Grade Ⅲ water quality	100	100
Noise standard coverage (%)	≥95	100	100	-	100	100	100
Service radius of 500 meters of public facilities coverage (%)	-	-	100 (sports facilities)	≥90	100 (bus station), other ≥ 80	100 (bus station)	≥ 90 (parkland)
Biodiversity	Native plants index ≥ 0.7, comprehensive species index ≥ 0.5	-	Native plants index ≥ 0.7	-	Native plants index ≥ 0.8	Native plants index ≥ 0.8	Native plants index ≥ 0.85, comprehensive species index ≥ 0.7
Heat island intensity	≤2.5	-	-	-	≤1.5	≤1.5	-

(℃)							
Per capita public green space (sqm)	≥12	≥11	≥12	20	≥16	≥7.5	-
Pedestrian zone speed (m / s)	-	-	-	-	≤5	≤5	-
Sunshine duration standard of residential area (%)	-	-	-	-	100	-	-
Remark	Square permeable land area ratio ≥ 50%						

Eco-city's public services need to achieve a certain standard, and different eco-cities have different standards. However, apart from the need to achieve the requirement of urban planning standards, the green park, public transport, cultural and sports facilities should also be better arranged. In order to protect the balance of ecosystems and biodiversity in the green parks, the native plants should account for 70% of green vegetation. Presently, the eco-city's green areas represent the urban green land visibility. Therefore, in the indicator system, 'per capita public green areas' is more than 12 square meters.

3.3 Eco-city Indicators under Economic and Social Development

In order to reduce environmental pollution, eco-cities mostly take the tertiary industry as the leading industry, high-tech and innovative technologies also attract widespread attention. For example, some indicators in the Tianjin eco-city, Wuxi Taihu New-city and Chongqing low-carbon city’s indicator system express the force requirement for green economic development. (Table 5)

© ASCE 2014

Table 5. Key Values of Economic and Social Categories Indicators

Eco-city / Indicators	National Ecological Garden City Standards (Provisional)	Eco-county, Eco-city, Eco-province construction indictors (Trial)	Sino-Singapore Tianjin Eco-city Indicator System	Tangshan Bay (Caofeidian) Eco-city Construction Indicator System	Wuxi Taihu Newcity National Low-carbon Eco-city Demonstration Area Planning Indicator System	Chongqing Green Low-carbon Eco-city Evaluation Indicator System (Trial)	Low-carbon Eco-city Indicator System, CSUS
The tertiary industry proportion of GDP (%)	-	≥40	-	-		high-tech industries≥ 40	≥51
Job-Housing Balance index (%)	-	-	≥50	-	≥40	≥30	-
proportion of affordable housing (%)	-	-	public housing allowances≥ 20	public housing allowances≥ 20	-	-	≥30
Proportion of green travel (%)	-	-	≥90	-	≥80	≥90	80
Social Satisfaction (%)	≥85	≥90	-	-	≥95	≥70	≥90
Proportion of accessibility (%)	-	-	100	-	100	100	-

The indicators about society are also important, which include the job-housing balance, green travel, social satisfaction and so on. The ‘Job-housing balance’ makes employment from the nearest residence. Therefore, reducing traffic commuting distance. [10] In general, the more jobs the city arranges, the bigger the job-housing balance index is. Currently, in the eco-city indicator systems in china, the 'job-housing balance index' is generally higher than 80%. To ease the city traffic pressure, the support of ‘green travel’ is a very effective management tool (Green Travel is the travel way that gives minimal impact on the environment). The proportion of green travel is more than 80% in China's eco-city. Through public rental housing policy, some eco-cities maintain affordable housing as a certain proportion. Thereby, enhancing social satisfaction.

4 Characteristics and Differences of Eco-cities

As we know urban planning and design should be based on the characteristics of city development and should solve urban problems according to local conditions. Although some cities consider eco-cities as the future vision, difference does exist between them. In order words, their targets are the same to reduce resource consumption, to maintain environment quality, to sustain economic development and to enhance social harmony. It is very important to take account of cities' characteristics, and it is the key to fulfill sustainable development.

(A) Focus on the city's characteristics

Many of the eco-cities in China are building cooperation with other countries, such as the Sino-Singapore Tianjin Eco-city and Tangshan Caofeidian Eco-city. When using overseas eco-technologies we should also focus on cities' characteristics. In coastal areas, such as Caofeidian eco-city, reducing water erosion is important. Therefore, indicator 'coastal engineering and desalination project' in the indicator system exists. Built on saline land, urban development of Tianjin Eco-city is limited by natural conditions, so there are indicator 'native plants' in the indicator system to protect biodiversity.

(B) Differences in the Scale of Eco-cities

There are currently more than 259 Eco-cities in China and most of them are newly built. Their planning areas and populations vary widely. For example, the planning area of Chongqing Yuelai eco-city is 3.4 square kilometers, and Wuxi Taihu eco-city's is 150 square kilometers. Certainly, different scales may affect the development directions. For instance, larger eco-cities may focus on industrial development, transport and housing, whereas, smaller eco-cities may be more concerned about ecology and green space. Combined with the concept of green building and green urban planning proposed in the 12th 'Five-Year Plan', that the future eco-cities in China will emphasize on some details. Including how to make the low-carbon or green target more practical, how to cooperate with green architectural design and how to enhance the implementation efforts. [11]

5 Conclusions

China has built a number of eco-cities, the size and the conditions of them vary widely. Depending on the different characteristics of the cities it is essential find the suitable ways of ecological improvement using the corresponding valid indicators.

(A) Indicator systems may represent the characteristics of the different stages of eco-city development. The early studies on eco-city tend to macro-guidance state the indicator system as the evaluation criteria. Currently, indicator systems focus more on the guidelines for eco-city planning and design.

© ASCE 2014

(B) Eco-city indicator systems follow four aspects: resource, environment, economy and society. Indicators are mainly based on resource and environment, circular economy and green industry which are the basis of eco-city development.

(C) China has built a large number of eco-cities, the indicator system can reflect their unique characteristics and find the direction for future development.

(D) Eco-city indicator systems needs to be improved for the actual construction and need to be better combined with urban planning and urban management.

References:

[1] Li Jingyuan, eds. The Report on the Development of China's Eco-cities (2012), Social Sciences Academic Press, 2012.
[2] Xia Chunhai. Comparative Study of Eco-City Indicator System. Urban Studies, 2011(1), pp.38-42.
[3] Zhou, N., G. He, et al. China's Development of Low-Carbon Eco-Cities and Associated Indicator Systems. Berkeley, California, USA, Lawrence Berkeley National Laboratory.2012.
[4] Dimensions and Metrics, Understand the Basic Elements of the Report. https://support.google.com/analytics/answer/1033861?hl=zh-Hans
[5] Wu Qiong, Wang Rusong, et al.The indices and the evaluation method of eco-city.Acta Ecologica Sinica, 2005(8), pp.2091-2092.
[6] Sustainable Cities International (SCI), Canadian International Development Agency (CIDA). Indicators for Sustainability: How cities are monitoring and evaluating their success, 2012, pp.33-34.
[7] Sino-Singapore Tianjin Eco-city Indicator System Research Group. Navigation of Eco-city: Decomposition and Implementation of the Sino-Singapore Tianjin Eco-city Indicator System. Beijing: China Architecture & Building Press, 2010.
[8] Qian Yi. Emphasis on the Development of Non-conventional Water Resources. Environmental Economy, 2004(11), pp. 17-18.
[9] Shen Qingji. Renewable Energy and Urban Sustainable Development. City Planning Review, 2006(7), pp. 10-12.
[10] Sun Bindong, Li Nanfei etc. A Study on the Impact of Job-Housing Balance on Commuting Travels: An Empirical Test of a Traditional Idea in the Field of Urban Planning. Urban Planning Forum, 2010(6), pp.56-58.
[11] Qiu Baoxing, eds. Considering Both Ideals and Realities: Chinese Eco-city Indicators System and Pilot Eco-city Initiates. Beijing: China Architecture & Building Press, 2012.

© ASCE 2014

The Urban Waters Federal Partnership: An Emerging Model for Revitalizing Urban Rivers and Communities

Rachel Muir[1]

[1]U.S. Department of the Interior, U.S. Geological Survey , 12201 Sunrise Valley Drive MS953, Reston, VA 20192; PH (703-648-5114); FAX (703-648-6859); email: rmuir@usgs.gov

ABSTRACT

The Urban Waters Federal Partnership, (UWFP), was initiated in 2011 and is comprised of an innovative coalition of fourteen Federal agencies that focus on both natural resources and economic development. The UWFP's purpose is to increase collaboration across the Federal government and with local partners to revitalize polluted urban waterways in under-served cities nation-wide. Its goal is to improve environmental quality and local economies. To date, eighteen partnerships have been created in diverse watersheds and urban environments. Restoring these highly impacted aquatic ecosystems and adjacent communities requires integration of aquatic science, social science, socio-economic knowledge and engineering. The purpose of this paper is to introduce the UWFP to the engineering community and provide an opportunity to network with these interdisciplinary and urban-based partnerships. As a case study, the Delaware River Urban Waters Partnership will be a focus of this paper and presentation.

INTRODUCTION

The majority of large cities in the United States were established and expanded around rivers and estuaries where they served as a resource for transportation and commerce, water for industry and manufacturing, and for drinking water. Port facilities, factories, warehouses and other commercial enterprises dominated urban river fronts through the middle of the last century in the United States but shifts in commerce, transportation, international patterns of industrialization and the need for public spaces for growing urban populations have altered urban rivers (Kibel, 2007).

While traditional uses and demands on urban rivers have declined, urban populations continue to grow rapidly, outpacing the growth of the nation as a whole. The nation's urban population increased by 12.1 percent from 2000 to 2010, which outpaced the nation's overall growth rate of 9.7 percent for the same period. Urban areas – defined as densely developed residential, commercial and other nonresidential areas – now account for 80.7 percent of the U.S. population, up from 79.0 percent in 2000 (U.S. Census, 2012). There is also demographic information showing that younger segments of the nation's population are moving into urban areas (LaFevre, 2014). At the same time, urban areas continue to include populations that are economically disadvantaged and for whom access to "destination" recreational locations, such as national and state parks, are more limited.

© ASCE 2014

Urban water conditions impact populations in adjacent, upstream, and downstream communities. Reconnecting people with urban waterways will result in economic, environmental and social benefits to those communities. Healthy and accessible urban waters help grow local businesses and enhance educational, recreational, and social opportunities in the communities through which they pass. Urban waters, which often serve as drinking water sources, are frequently polluted from upstream sources and by runoff from roads and parking lots and industrial sources. Protecting them can help to protect the public and environmental health of these communities.

THE URBAN WATERS FEDERAL PARTNERSHIP

The UWFP is committed to working with local communities to restore waterways and reconnect people in urban communities with their rivers, lakes, wetlands, aquifers, estuaries, bays, and oceans. The UWFP was created in 2011 to recognize and act upon long-standing needs to revitalize and urban waters and the communities that surround them and to anticipate increasing demands for the environmental and recreational services that urban waters have the potential to provide (Urban Waters Federal Partnership, 2011). Since it began fourteen Federal agencies and scores of local public and private partners have joined in creating eighteen partnerships in urban communities across the nation. Seven partnerships were initiated in 2011 and an additional eleven were added in 2013. The current eighteen partnerships and their locations and additional information available through the web are listed in Table 1, below.

THE PARTNERS

The Federal agencies and private partners that have been brought together through this partnership reflect the diverse capacity and skills, resources and capabilities to achieve the goals of this national Partnership and serve the communities within the individual partnerships. For example, the capabilities and expertise of the Federal partners listed below can benefit local communities through:

- the potential of a partnership that includes the resources and expertise in natural resources management, engineering and science to manage and restore urban rivers and their aquatic life through departments and agencies such as U.S. Environmental Protection Agency NOAA, the Army Corps of Engineers, and the U.S. Department of Interior and it agencies such as the Fish and Wildlife Service, National Park Service and U.S. Geological Survey;
- the expertise on urban forests, stream restoration and community gardens such as the U.S. Department of Agriculture and Forest Service can provide;
- the know-how to address infrastructure and energy needs that the U.S. Department of Transportation and the U.S. Department of Energy and Army Corps of Engineers can bring to bear to assist local partners;
- the social, economic, educational, and human health support that the Corporation for National and Community Service, the U.S. Departments of Education, Health and Human Services and Housing and Urban Development can bring to local communities.

By improving coordination among these diverse Federal agencies and effectively linking the agencies with local communities and organizations to address needs that are identified by those local communities the UWFP can be an agent for change in our urban centers.

© ASCE 2014

Table 1. Urban Waters Federal Partnership locations, year initiated and website information.

Partnership	Location	Year Begun	Website
Anacostia Watershed	Washington DC/Maryland	2011	http://www.urbanwaters.gov/anacostia/index.html
Big River and Meramec Rivers	Saint Louis, MO	2013	http://www.urbanwaters.gov/
Bronx and Harlem Rivers	New York	2011	http://www.urbanwaters.gov/bronx-harlem/index.html
Grand River Grand Rapids	Michigan	2013	http://www.urbanwaters.gov/grandriver-rapids/index.html
Greater Philadelphia Area	Delaware River Watershed, (PA, NJ, DE)	2013	http://www.urbanwaters.gov/delaware/
Green and Duwamish River	Seattle, WA	2013	http://www.urbanwaters.gov/
Lake Pontchartrain Area	New Orleans	2011	http://urbanwaters.gov/nola/index.html
Los Angeles River	Los Angeles, CA	2011	http://www.urbanwaters.gov/la/index.html
Martin Pena Canal	San Juan, Puerto Rico	2013	http://www.urbanwaters.gov/
Middle Blue River	Kansas City, MO	2013	http://www.urbanwaters.gov/
Middle Rio Grande River	Albuquerque, NM	2013	http://www.urbanwaters.gov/mid-riogrande/index.html
Mystic River Watershed	Massachusetts	2013	http://www.epa.gov/mysticriver/index.html
Northwest Indiana Area	Indiana	2011	http://www.nrs.fs.fed.us/partners/nwiuw/
Passaic River	Newark, NJ	2013	http://www.urbanwaters.gov/
Patapsco River	Baltimore, MD	2011	http://www.urbanwaters.gov/baltimore/index.html
Proctor Creek Watershed	Atlanta, GA	2013	http://www.urbanwaters.gov/proctor/index.html
South Platte Watershed	Colorado	2011	http://www.urbanwaters.gov/splatte/index.html
Western Lake Erie Basin	Toledo, OH	2013	http://www.urbanwaters.gov/lake-erie/index.html

© ASCE 2014

GOALS, CHALLENGES AND SOLUTIONS FOR THE URBAN WATER FEDERAL PARTNERSHIP

The UWFP has proposed guiding principles to assist each individual partnership revitalize their urban water resources and the communities that surround them. These include:

- Promote clean urban waters;
- Reconnect people to their waters;
- Promote water conservation;
- Use urban water systems as a way to promote economic revitalization and prosperity;
- Encourage community improvements through active partnerships;
- Be open and honest, and listen to communities, knowing that this is the best way to engage and learn from them;
- Focus on measuring results and evaluation to fuel future success.

It should be clear from examining these principles that they focus on natural resources and human resources in equal measure. Success to date on the part of the UWFPs has depended on creating an organization and communications that values both communities and their natural resources and is effective in connecting them. Below is a brief examination of one principle -- the principle of promoting clean urban water – and the challenges to this principle or goal and the solutions that are being put into play among the Partnerships:

Principle/Goal: Promote Clean Urban Waters. Clean water is a foundation for sustainable communities and healthy ecosystems and the watershed is the fundamental planning unit for water quality protection. One challenge for urban river restoration in achieving the goal of clean water is that it requires cooperation among communities and governments throughout a watershed, from headwater to estuaries. This is particularly true for urban rivers since they are frequently at the mouth or estuarine portion of rivers and streams and reflect the impacts of upstream activities as well as local environmental impacts.

Challenge: Urban Impacts on Rivers and Streams. Urban rivers and streams present unique challenges to restoration in addition to being at the receiving end of upstream environment impacts. The high amount of impervious surface cover in urban areas leads to decreases in the absorption of precipitation into groundwater and increases surface flow and peak flows of run-off. It has been known for some time that flood discharges are much higher in urban watersheds than forested watersheds of comparable size; Seaburn (1969) measured flood discharges 250% greater in urban catchments than forested catchments. This adversely alters the hydrology of urban rivers and streams, increasing their capacity to erode and destabilize river channels and banks (Booth and Jackson, 1997). These changes, plus loss of natural streamside vegetation and wetlands to development, result in decreased capacity to absorb nutrients and detoxify pollutants. Unstable flows, increased pollutants and loss of suitable habitat that are typical of urban watersheds cause declines in the richness of fish communities and the invertebrate and plant and algal communities that support them (Paul and Meyer, 2001)

© ASCE 2014

Solutions: What Urban Waters Federal Partnerships Can Provide:

- **Organization**. The agencies and organizations collaborating in each UWFP have a combined expertise and technical capacity to address these challenges to improve water quality as well as the local knowledge to address these issues effectively. It could be argued that these agencies had this capacity before the formation of the National UWFP. However the UWFP has been effective in breaking down silos among agencies, engaged community-based organizations, leveraging local assets and authorities and collaborating at the regional level. Breaking down these silos and increased collaboration is a prerequisite to improving water quality throughout a watershed.

- **Developing New Tools and Technology.** Agencies and local partners have developed mapping tools and GIS capabilities to pinpoint potential restoration sites. For example, the Patapsco River (Baltimore) Partnership has connected with the Baltimore Neighborhood Indicators Alliance and, with the support of the U.S. Forest Service, to has developed a map of community-managed open space depicting the location of open spaces, community gardens and even vacant lots with the potential to be converted to "green" uses as well as their distance from the nearest stream in the watershed to assist partners in prioritizing efforts to improve watershed and ecosystem health, (For more information and to see mapping products visit http://water.bniajfi.org/). The U.S. Forest Service has made available evaluation tools for urban forestry that can guide decision-making in determining ecosystem and other services provided by urban trees. A software program and supporting information called "i-Tree", (see https://www.itreetools.org/), is one such tool that is being used by UWFPs. By understanding the local, tangible ecosystem services that trees provide, i-Tree users can link urban forest management activities with environmental quality and community livability.

- **Connection.** Every individual UWFP has made connections with residents within their watershed as a first step in establishing the partnership. These local partnerships are what make the UWFP viable and sustainable. As part of the national planning for the UWFP each individual partnership has an "ambassador" position whose major duty is to establish and coordinate among the local partners and Federal partners. The Partnerships are already demonstrating significant progress in connecting to local communities and engaging them. For example, The Anacostia Urban Waters Federal Partnership has brought together many community organizations in both Maryland and the District of Columbia to assist in the restoration of the Anacostia watershed and their communities. The Anacostia Partnership has worked with Earth Conservation Corps, (ECC)**,** a nonprofit youth development and environmental service organization located in Southeast Washington, DC. ECC has provided hundreds of unemployed and out of school youth ages 17-25 with hands-on workforce and leadership development training, environmental education and media arts training.

© ASCE 2014

A CASE STUDY: THE DELAWARE RIVER URBAN WATERS FEDERAL PARTNERSHIP

The Resource

The Delaware River Urban Waters Federal Partnership, (Delaware Partnership), was one of the recently established partnerships in 2013 and is an ambitious undertaking; the partnership includes four cites in three states; Philadelphia, PA; Camden, NJ; Chester, PA and Wilmington, DE. The Delaware River watershed drains an area of 14,119 square miles (36,570 km^2) and encompasses 838 municipalities in five U.S. states—New York, New Jersey, Pennsylvania, Maryland, and Delaware. The Delaware drainage provides drinking water to 17 million people—roughly 6% of the population of the United States (Philadelphia Water Department, 2013). The Delaware is a river of many uses; sustaining fishing, transportation, power, cooling, recreation and in regard to transportation is the number one river in regards to total tonnage. However, with no dams or impediments on the river's mainstem, the Delaware River is one of the few remaining large free-flowing rivers in the United States and continues to support diverse fish and wildlife populations. As a result the river maintains anadromous fish populations such as shad and eels and recently breeding Atlantic surgeon have been identified in the lower river. These economically important species pass through the urban areas within the partnership and maintaining water quality and habitat sufficient to sustain these species is recognized as an important goal for the Delaware Partnership.

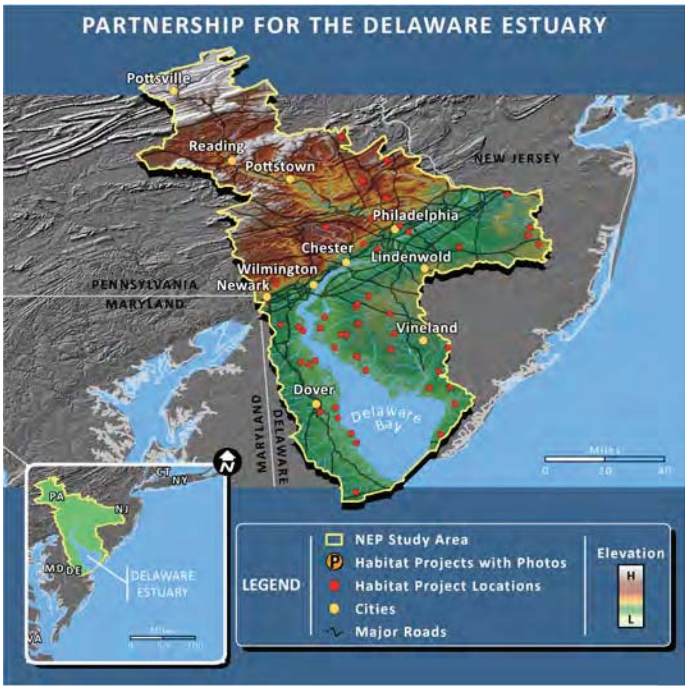


Figure 1. The Delaware River Watershed. The four major cities in the geographic reach of the partnership are located in the center of the watershed; Philadelphia and Chester in Pennsylvania, Wilmington, Delaware and Camden, New Jersey. Also shown are habitat restoration projects conducted by two members of the Partnership, The U.S. EPA Estuary Program and the Partnership for the Delaware Estuary. The Delaware River Urban Waters Partnership is working to coordinate and support restoration and community-based projects throughout the Partnership that are responsive to each community's needs and priorities. (Graphic used with permission of the Partnership for the Delaware Estuary.)

Developing a Model for Cooperation The Delaware Partnership, under the leadership of Ambassador Michael Leff of the Philadelphia Field Station of the USDA Forest Service and the Davey Institute, formed a core team of Federal partner planners, (including the U.S. Forest Service, U.S. National Park Service, U.S. National Oceanographic and Atmospheric Administration, U. S. Geological Survey, U.S. Environmental Protection Agency, U.S. Army

Corps of Engineers and the U.S. Fish and Wildlife Service). Each Federal partner brought together the constituents they most commonly work with to the table and involved them in planning a series of workshops in each individual community in June of 2013. Through these community-based meetings priorities for restoration were identified for each community. In a subsequent "All Partners Meeting" held in in April of 2014 a partnership-wide meeting set of five priorities or "Communities of Practice" was identified by partners and stakeholders. These included:

- Water Quality and Quantity
- River Protection and Restoration
- Climate Resilience
- Brownfields Revitalization
- Trails and Open Space

A brief, (5 minute), summary of the All-Partners meeting, its organization and content can be found on YouTube at: https://www.youtube.com/watch?v=ionrAl4bfuQ.) These Communities of Practice have become an engine for identifying, organizing and implementing projects for the Delaware Partnership. The Core Team has continued serve the shared needs of the partnership, such as establishing a website (http://www.urbanwaters.gov/delaware/) with support from the U.S. Environmental Protection Agency, and to act as a conduit for information between the Delaware River Partnership and the National Partnership.

The results of this "partners-first" approach includes connecting over 115 Federal, State, municipal, nonprofit, community, academic and private agencies and organizations with the Delaware Partnership. The Delaware Partnership is working on issues as large as stormwater issues in its largest metropolitan areas and planning for implementation of projects to resist strong storms to local green infrastructure projects and community gardens. The Delaware Partnership has also begun to attract modest grant funding, which in many cases may be matched with funds or in-kind from among its partners.

SUMMARY

This paper is an overview into the Urban Waters Federal Partnership as a whole and a brief glimpse into the development of a single urban partnership. While these nationally-based Partnership efforts provide the groundwork for collaboration, each individual Partnership is an ongoing experiment in securing the vision of protecting and restoring America's urban waters and reconnecting our urban citizens to their water resources. The partnerships place a special emphasis on supporting underserved or economically distressed communities. Tangible goals are being realized in modest but measurable steps through the Urban Waters Federal Partnership.

Connecting with a professional organization such as the American Society of Civil Engineers provides a connection between the UWFP and with the engineering community and adds to the skills needed to address one of the Nation's most pressing domestic issues; adapting our cities to become more sustainable and more healthy for its citizens during a period of rapid demographic and climate change. The UWFP is one model for collaboration to increase sustainability. The challenges – in science and technology as well as the social, economic and policy arenas – are significant, particularly in an economically austere period for our nation. However, these are

© ASCE 2014

conditions similar to under which the most sustained and successful innovations in protecting public resources may emerge. The establishment of the America's national parks occurred directly after the Civil War, (Burns and Dalton, 2009). Similarly, the concept of applied wildlife management emerged out of a period of a precipitous loss of natural resources during the Great Depression as was articulated by Aldo Leopold in Sand County Almanac (Leopold, 1949). However, the resiliency of nature and a reason for optimism and its ability to recover from degradation is perhaps best stated by the late Rene Dubos:

"There is a phenomenal resiliency in the mechanisms of the earth. A river or lake is almost never dead. If you give it the slightest change…then nature usually comes back."

REFERENCES

Booth, D. B., and C.R. Jackson, (1997). Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation. J. Am. Water Resour. Assoc. 33:1077-90.

Burns, K., and Dalton, D., (2009). The National Parks: America's Great Idea, Knolf, New York *and* http://www.pbs.org/nationalparks/.

Dubos, R. J., (1981). Celebrations of life, McGraw-Hill, New York.

Kibel, P.S., (2007). Rivertown: rethinking urban rivers, GGU Law Authors, San Francisco.

LeFevre, C., (2014). With historic influx of urban residents, cities are seeing growth in amenities"
http://www.popcitymedia.com/features/completecities062714.aspx, (July 16, 2014).

Leopold, A., 1949. A Sand County Almanac, Oxford, New York.

Paul, M.J., and J.L. Meyer (2001). Streams in Urban Landscapes. Annual Rev. Ecol. Syst., 32:333-65.

Philadelphia Water Department, (2013). Moving from assessment to protection…The Delaware River watershed source water protection plan (PWSID #1510001), (July 17 2013).

Seaburn, G.E., (1969). Effects of urban development on Hydrology and Some Effects of Urbanization on Long Island, New York: Vol. 627 of U.S. Geological Survey Professional Papers, U.S. Government Printing Office, Washington, DC.

Urban Waters Federal Partnership, (2011).
http://www2.epa.gov/sites/production/files/documents/urbanwaters-factsheetv2.pdf. (July 13, 2014)

U.S. Census, (2012). Growth in Urban Population Outpaces Rest of Nation, Census Bureau Reports", http://www.census.gov/newsroom/releases/archives/2010_census/cb12-50.html/, (March 26, 2012).

© ASCE 2014

THE CONSTRUCTION OF SUSTAINABLE DEVELOPMENT INDICATOR SYSTEM OF GREEN BLOCKS

ZANG Xinyu[1]; CHENTian[2]; WANG Qiao[3]

[1]Department of Urban Planning, School of Architecture, Tianjin University, P.O. Box 300072, Tianjin China, FAX 87470298, email: zangxinyutju@126.com
[2]Department of Urban Planning, School of Architecture, Tianjin University, P.O. Box 300072, Tianjin China, FAX 87470298, email: chentian5561@vip.sina.com
[3]Department of Urban Planning, School of Architecture, Tianjin University, P.O. Box 300072, Tianjin China, FAX 87470298, email: wanzi-aa@163.com

ABSTRACT

Based on the current research progress of indicator system for sustainable development and the characteristics and development trends of the eco-city's construction around the world, the study establishes a sustainable development indicator system for green blocks in eco-cities, including elements selecting, concrete contents determining, strategies, measurement and correction of the indicator. Meanwhile, through questionnaire survey, this research summarizes the weights of sustainability indicators in green blocks, which may provide a scientific and effective guidance for the planning and construction for eco-cities, and puts forward feasible ecological design strategies of green blocks.

KEYWORDS: eco-city, green blocks, sustainable development indicator system, ecological urban design strategy

1. The Connotation and Application of Sustainable Development Indicator

The report of World Commission on Environment and Development defined sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs," which has been accepted by academia since 1987[1].Sustainable development is a fundamental principle for ecological urban design, is also the key idea to solve a series of economic and social problems, including shortage of resources, environmental pollution, and overpopulation caused by urbanization. With the deepening of the research of urban sustainable development theory, the concept of sustainable development has already covered land use, urban transport, urban ecology, social justice, socio culture issues and so on. The research regarding this topic has provided profound theoretical and technical support for the ecological urban design.

---

[1] United Nations. 1987."Report of the World Commission on Environment and Development." General Assembly Resolution 42/187, 11 December 1987.

© ASCE 2014

Proposed in 1960s and 1970s, the sustainable development indicators constituted city indicators system, which were based on the concept of sustainable development. Sustainable development indicators were initially used to study the development of urban society, urban status and trend evaluation, etc.[2] With the expansion of the scope of application, these indicators were gradually applied in resources, environment, economy, social issues and other fields. For instance, the sustainable development indicator system of Seattle in 1993 is a representative case. It presents 40 indicators to guide its sustainable development for urban economy, society, resources and environment.

In 1996, the Canadian scholar Maclaren proposed that sustainable development indicator system should be more comprehensive, forward-looking, distributive and extensive. He also came up with 6 structure types for sustainable development indicator, which could be considered as the foundation for studies on the structure of indicator system[3]. Since then, sustainable development indicators began to be used in guiding the development of urban communities, discussing how to combine community development and local characteristics with sustainable development indicators on the basis of an integral system, and reducing the procedures and the complexity of its implementation[4].

2. The Characteristics of International Eco-city Indicator System

With the rise of eco-city planning, the application of sustainable development indicators in the eco-city indicator system became more comprehensive. Currently, sustainable eco-city construction and studies of sustainable development indicators in the United States, Germany, Finland, the Netherlands, Sweden and other countries and regions have made remarkable achievements. Eco-city indicator systems generally have the following characteristics:

（1）To formulate a indicator system needs a long period, and requires dynamic update mechanism.

To develop eco-city indicator system, it normally requires a relatively longer period and quite a lot effort, including statistics, collation and analysis on the city's natural, economic, social status and future trends. Then it might be possible to scientifically predict the content of indicators, make dynamic updates, and form indicator effective implementation strategies. For example, Heidelberg, German began to develop goal-oriented urban development

---

[2]Bu Xueyang, Yun yingxia(2011). Community public space planning directed by sustainable development indicator— a case study based on Wei an nan li residential district public open space renewal [J], City planning review, (4):85-89.

[3]Maclaren V. W(1996). Urban sustainability reporting[J]. Journal of the American Planning Association, 62(2): 185-202.

[4]Anke Valentin, Joachim H. Spangenberg (2000). A guide to community sustainability indicators [J].Environmental Impact Assessment Review, (20): 381–392.

© ASCE 2014

planningfrom1997, and formed integral city sustainable development indicator system until 2004, comprehensively covering urbanization goal, employment, housing, environment, population, society, civilization and other fields[5].

（2）Indicators must be defined for both short-term and long-term developments, and the effectiveness of the indicator contents have to be emphasized.

The content of the eco-city indicator system should correspond with the city's development goals and planning sequence. Therefore some indicator contents that based on city's natural, economic and social situation should be achieved in near future. While, based on city's potential ability and development direction, other indicator contents cities' need longer period to be achieved. In order to formulate specific implementation measures, target indicator could be divided into many component indicators which are easier to implement. In 1995, the national environmental protection bureau and the sustainable development of the university of Massachusetts center jointly established the guidance for sustainable community indicators, totally 104 in 12 categories, including economy, environment, resources, society and so on[6].Based on the dispersed layouts of American towns, the importance of various indicators are decomposed step by step and identified through weights, in order to make its content more practicable and maneuverable[7].

（3）Improve the Supervision of the Indicator, Advocate Public Participation

It is necessary to establish supervision mechanisms, which are normally consisted of two parts, the supervision of government departments and public oversight. It can use information technology to implement tracking, statistics, sorting and analysis, aiming at the status quo of the eco-city construction and degree of the realization of the indicators. Meanwhile, information would be surmised in annual survey reports which should be published to local governments and the public. Accordingly, effective feedback mechanisms should be set up through hearings, seminars and other forms of public participation which may get people's opinions and comments.

3. The Research Progress of Eco-city Indicator System in China

Eco-city indicator system is the core part of eco-city planning and construction and the foundation of successful eco-city implementations. Eco-city indicator system is complex, which needs comprehensive consideration of regional status, the national policy, ecological conditions, and economic and social development factors.

---

[5]Heidelberg Sustainability Report 2004-Indicator-based success rate of the City Development Plan Heidelberg, 2010.

[6]Maureen Hart. Guide to Sustainable Community Indicators [M]. May 1995 (www. sustainable measures. com/)

[7]Fang Jiande, Yang Yang, Xiong Li(2010). "Comparison of international and domestic indicator systems for urban sustainable development evaluation." J. Environmental science and management, 35(8): 132-136.

© ASCE 2014

3.1 The Research Status of Eco-city Indicator System in China

The eco-city indicator system in China is formulated by learning the advanced experience from other countries and regions. So it is still in initial stage. Regarding the development and implementation of eco-cities, indicator system, Sino-Singapore Tianjin Eco-city and Tangshan Caofeidian Eco-city might be two examples in China. Both of them carried out detailed investigation and study, adopt strict expert demonstration. Meanwhile, their systems are evaluated and divided into many detailed indicators, so as to formulate concrete implementation strategies, which are also easy to operate. Although the indicators of these two cities could not be fully applied, both of them have achieved good results in the intensive utilization of resources and ecological environment protection. These two cases might have positive and referential meanings for other cities in China.

Sino-Singapore Tianjin Eco-city is the first officially built eco-city in China. A system with a combination of the qualitative indicator and quantitative indicator was set up, which mainly covers the social, economic, environment and resource. The system contains 26 items, including 22 controlling indicators and 4 guiding indicators. (Table1)

Table1 The indicator system of Sino-Singapore Tianjin Eco-city（Controlling indicators）

	Index layer	**Serial number**	**Second grade indicator**	**Units**	**Indicator value**	**Time limit**
Ecological and environmental health	Good natural environment	1	Ambient air quality	Days	Equal to the secondary standard≥310 days	Starting today
				Days	SO_2 and NO_x are equal to the level of standard ≥150 days	Starting today
					Meet the “ambient air quality standard” (GB3095-1996)	2013
		2	Surface water quality		Meet the “surface water environment quality standard” (GB3838-2002)	2020
		3	Compliance rate of tap water	%	100	Starting today
		4	Noise compliance rate	%	100	Starting today
		5	Carbon emissions intensity per unit of GDP	Ton - C/millions of us dollars	150	Starting today
		6	Natural wetland net losses		0	Starting today
Social harmony and	Coordination artificial	7	The proportion of green building	%	100	Starting today

progress	environment	8	Native plants index		≥0.7	Starting today
		9	Per capita public green	m^2/ person	≥12	2013
	Healthy life style	10	Daily water consumption per capita	Litre/person day	≤120	2013
		11	Garbage output per capita	Kg/person-day	≤0.8	2013
		12	The proportion of green travel	%	≥30	Before 2013
	Perfect infrastructure	13	Waste recycling rate	%	≥90	2020
		14	Free style facilities worldwide residential area ratio around 500 m on foot	%	≥60	2013
		15	Municipal pipe network penetration	%	100	2013
		16	Barrier-free facilities coverage	%	100	Starting today
		17	Municipal pipe network penetration	%	100	2013
The economical efficiency	A sound management mechanism	18	Affordable housing and low-rent housing accounted for the proportion of the total in the residence	%	≥20	2013
	Continued economic development	19	Utilization of renewable energy	%	≥20	2020
		20	Utilization of non-conventional water resources	%	≥50	2020
	Active science and technology innovation	21	Housing balance index of employment	man-year	≥50	2020
	Overall balance of employment	22	Housing balance index of employment	%	≥50	2013

Tangshan Caofeidian Eco-city is under the strategic goal of further development in bohai sea economic zone. Learning from the experiences and lesson from Tianjin Eco-city, the indicator system of Tangshan Caofeidian Eco-city may be more comprehensive. It mainly covers the economic, environmental and social aspects, totally 141 items, including 109 planning indicators and 32 administrative indicators. (Table 2)

Table 2 The indicator system of Tangshan Caofeidian Eco-city（Excerpts）

Indicator classification		**Sweco-The overall indicator System 7: landscape and public space**				**Definition of indicator**
		Serial number	**Indicator**	**Value**	**Units**	
System 7: landscape	**The quality of natural**	130	Share of total area (contains water) green	35	%	City green coverage rate

© ASCE 2014

and public space	**environment and the city**		space structure			
		131	Per capita public green area	20	m^2/ person	Per capita public green area
		132	The proportion of forests or trees in green space	25	%	The arbor coverage in green space
		133	The proportion of wetlands or natural ecological environment in green space	20	%	Proportion of wetlands and natural growth of biota in green space
		134	The proportion of investment used to restore the stream water quality in a total investment	0.1	%	The proportion of investment used to restore the stream water quality in a total investment
	Accessibility of parks and public Spaces	135	Area ratio of residential area that could reach the public space around 500m	100	%	Ratio of residential area with public space around 500m
		136	Ratio of residential area that could reach theparks and public spaces where noise level is lower than 45 dB around 3000m	100	%	Ratio of residential area withparks and public spaces where noise level is lower than 45 dB around 3000m
		137	Ratio of residential area that could reach the small green space around 50m	100	%	Ratio of residential area with small green space around 50m
		138	Ratio of residential area that could reach the neighborhood green space (1-5ha) around 200m	100	%	Ratio of residential area with neighborhood green space around 200m
		139	Ratio of residential area that could reach the district green space (1-5ha) around 500m	100	%	Ratio of residential area with district green space around 500m
		140	Ratio of residential area that could reach the urban green space around 1000m (>10ha)	100	%	Ratio of residential area with urban green space around 1000m (>10ha)
		141	Ratio of residential area that could reach the coast line or the river banks around 1000m	100	%	Ratio of residential area with the sea or river waterfront around 1000m

3.2 The Development Trend of China's Eco-city Indicator System

With the rapid development of China's ecological city construction, indicators about green ecological system are becoming more and more various, which could bring problems in terms of operation and implementation for governments. Therefore, for practical purposes, sustainable ecological indicator system should be set up according to the actual situation of eco-city in different regions.

First of all, the content of the ecological indicator system should be adapted to the different

© ASCE 2014

stages in planning system, such as strategy planning, master planning, detailed planning and architectural design. In other words, it should correspond with urban development in multi levels, including regional level, urban level, neighborhood level and individual building level. ,

Secondly, efficient and concise evaluation of green ecological indicator should be carried out based on the cost estimation of ecological indicator which is dominated by the government. According to the characteristics and actual situation of natural elements in different regions, ecological indicators should be dismantled, supervised and evaluated. Especially, it should pay more attention to the construction of the sustainable development indicator system of green blocks, and ensure each of the construction of actual project could embody the green or ecological principle in a certain extent.

Finally, it is important to avoid to blindly follow "only on the ecological indicator theory" and to introduce the "ecological effectiveness" principle and the ecological system of incentives in planning. For example in Seattle, plazas, green-parks, roof gardens and atriums had all been constructed in a large-scale since the introducing the incentives of FAR in 1960s.Although there were only a few of indicators and guidelines, the principle of ecology have been carried out in action and the green ecological purposes have been achieved[8].

4. Building a Sustainable Indicators System of Green Blocks

Based on its own target and the principle of sustainability, the sustainable development indicator system of green blocks should integrate element selection, the specific content of indicators, implementation strategy, the indicator evaluation and correction, etc. In the process of building eco-city, neighborhood-level indicators of sustainable development should follow city-level indicator contents and ecologically sustainable urban design ideas at the middle-scale and provide building strategy and the effectiveness of the planning technical support for the development of eco-city.

4.1 The Basic Framework of Sustainable Development Indicators of Green Blocks

Based on the specific characteristics of different neighborhoods, the sustainability indicators of green blocks should focus on the goal of sustainable development, the comprehensive analysis and evaluation of the various neighborhoods in terms of their economy, environment, social status, policy and other factors; and accordingly determine basic indicators, core indicators and flexible indicators and finally constitute the realities indicator system of green blocks finally. Its basic structure should be.

（1）Basic Indicators. It is based on the master planning, a comprehensive analysis of the city's geographical location, resources, economic development level, policy-oriented and other

[8]Wu Jingwen(2007). Valid open space forming by economic lever—taking the far awards for example[J].Huazhong Architecture, (06):89-90.

© ASCE 2014

factors. We can make a basic sustainable development indicators system, it mainly represents for the target layer in the indicator system.

（2）Core Indicators. It is based on detailed planning, according to the basic indicator to determine the objectives, combining different neighborhoods natural conditions, geographic conditions, traffic conditions, the function of the block and other factors to formulate a core indicator of sustainable development. The main performance is the control layer in this indicator system.

（3）Flexible Indicators. It combines the realistic conditions of city level and district-level, and forecasts the potentials for future development in neighborhoods in order to develop some flexible indicators in system. It is mainly for the guiding layer.

4.2 The Element Selection of Sustainable Development Indicators of Green Blocks

Regarding the evaluation and selection of elements, we should pay attention to distinguish the background elements and block specific elements. In general, the neighborhoods located in the same city tend to have the same economic, social, cultural, policy, and macro-climatic and environmental conditions, which may constitute the background elements and also could be considered as the basis of basic indicator; while the micro-level conditions such as location, traffic conditions, local micro-climate, natural vegetation, rivers and other environmental elements may constitute the block specific elements which establish the core indicators and flexible indicators of green blocks as the foundation conditions. The background elements can generally be seen as the same for blocks in the same city, so the green block indicator system should be established through investigating and analyzing the advantages and disadvantages of background elements firstly, and then choosing the key elements of sustainable urban development in order to guide the formulation of the basic indicators in green blocks. (Table 3)

Table 3 Key elements of sustainable development indicators of green blocks

Project	Sub-element	Detail	Be Affected the Representativeness of the Indicators
Background elements	Urban climate factors	Environment of Wind, thermal, sound, etc.	Ambient air quality, noise compliance rate, etc.
	Urban natural environment	Topography, land carrying capacity, compatibility of land, vegetation, water bodies, etc.	Per capita public green space, surface water, etc.
	Urban economic development level	Urban GDP, the level of public resources, infrastructure construction, etc.	Municipal pipe network penetration, renewable energy utilization, utilization of non-conventional water resources, etc.
	Urban social and cultural environment	Educational status, values, customs, religion, etc.	Compulsory penetration per capita years of education, culture and other special funds , etc.
	Urban public utilities	Public facilities, housing, education, health, hygiene, etc.	Employment and housing balance index, affordable housing, low-rent housing accounted for the total proportion of residential , etc.
	Urban	Urban management and	Carbon dioxide emissions, protected

© ASCE 2014

	policy-oriented	control, land, transportation, environmental protection, housing, social welfare policy, etc.	areas (including wetlands) proportion of total land area , etc.
	The city's technological level	Life science, space science, physics, chemistry, biotechnology, etc.	Researchers accounted for the proportion of the employed population, the rate of sewage centralized treatment and water reuse , etc.
concrete elements	Microclimate of blocks	Block-level local wind environment, thermal environment, sound environment, etc.	Local air quality, the comfortableness of the space, noise rate of reaching the standard, etc.
	Natural environment of blocks	Micro-topography of blocks, vegetation, water bodies	Air quality, water quality, rainwater recovery, neighborhood green space per capita rate , etc.
	Location conditions of blocks	Geographic location, transportation, resources, etc.	The proportion of green travel, the proportion of residents with public service facilities around 500m, etc.
	Function of blocks	Residential land, commercial land, cultural land, educational land, health care land, public green spaces, etc.	Functional area noise compliance rate, per capita area of public buildings, etc.
	space form of blocks	The dimensions, capacity, building materials, volume, color of blocks, etc.	Intensity of land use, density of urban development, floor area ratio, environmental comfort, space diversity, etc.

4.3 The Concrete Contents of Sustainable Development Indicators of Green Blocks

With the influence of economics, resources, technology and policy, it is more appropriate to select elements according the indicators with reference to other countries and regions on sustainable community indicator system construction experience. It is very important to select elements based on other counties' experience. Under normal circumstances, indicators that the traditional planning methods and means can be achieved by passive technology but it may have to pay higher economic and resource costs to by using active techniques. We may consider postponing the choice (the premise is that can exchange for long-term environmental and resource benefits). With reference to Sino-Singapore Tianjin Eco-city(SSTEC) and Tangshan Caofeidian Eco-city, the basic elements of basic indicators, core indicators and flexible indicators can be effectively confirmed by following the indicator principle of preference, according to the block indicator system feature selection method, the corresponding indicator target layer, control layer and a guide layer; and thus a indicator system is established in the economic, social, environmental three large systems for determining the specific content of indicator system in green blocks to provide guidance (Table 4).

Table 4 The contents of sustainable development indicator system of green blocks

	First Grade Indicator	**Second Grade Indicator**	**Third Grade Indicator**
Basic	Economy	Population, housing,	Energy demand and supply; The

© ASCE 2014

Indicators （Target Layer）		transportation, energy, commerce, tourism, etc.	sustainable development of house; Non-traditional water utilization; Housing balance employment index; Per million labor force in the R&D of scientists and engineers full-time equivalent;
	Society	Social justice, culture, education, health, science and technology level, etc.	The accessibility of public space and facilities; Daily water consumption per capita life; Daily garbage output per capita; Barrier-free facilities rate; Affordable housing, and low-rent housing accounted for the proportion of the total in the residence;
	Environment	Air quality, land resources, water resources, waste disposal, recycling of resources, etc.	Resource efficiency; In ambient air quality. The surface water environment quality. Compliance rate of tap water; Functional areas noise success rate; Per unit of GDP carbon emissions intensity; Natural wetland net losses;
Core Indicators （Control Layer）	Economy	Stable economic growth, promoting local economic vitality	Renewable energy utilization; Green building proportion; Transportation accessibility; Traffic safety; Public transport and walking, bicycle transportation ratio;
	Society	Promoting a vibrant social life and enhancing the efficiency of public services	Diversity in public places and mixed use; free style facilities worldwide residential area ratio around 500 m on foot; Recycling utilization; Municipal pipe network penetration;
	Environment	Regional ecological security, natural ecological environment, safe living environment and local cultural environment	Accessibility of parks and public Spaces; Native plants index; The per capita public green space;
Flexible Indicators （Guide Layer）	Economy	Economic development with low energy consumption, diversification and efficient	Transport system efficiency and the environment; Environmental health;
	Society	To enhance public participation and encourage people to personal development	Proportion of green travel; Waste and life rubbish (harmless) rate;
	Environment	Ecological diversity	The protection of biological diversity

Combined livable city scientific evaluation criteria, China Habitat Environment Prize evaluation index system (pilot), and the concrete Contents in the indicator system of Hamer over Lake Ecological City in Swedish, Sino-Singapore Tianjin Eco-city, Tangshan Caofeidian Eco-city, Wuxi Taihu New City and other typical eco-cities, a survey questionnaire about the sustainable development indicator system of green blocks had been formed (see Appendix). The survey was taken by expert investigators, which selected 54 professionals with graduate degrees as questionnaire survey objects, including teachers, students, planning and design personnel. Through the analytic hierarchy process (AHP) with the result of questionnaire, all levels of indicator weights value can be obtained, thus showing the importance of the different types of indicators. It can be seen that the environment class indicator weights are highest, 0.53959, and the weight of social class indicator followed as 0.297005, economy class indicator weights lowest

© ASCE 2014

0.1634 from First grade indicator. So it can be concluded that the environment should be the most important indicators (Table 5).

Through the weights of sustainability indicators in green blocks, it can clarify the orientation of planning and design, and determine the specific content of green blocks and measures. Nevertheless, the drafting of sustainable indicator systems in green blocks is still a complex task. It is still unknown whether the content of the indicator system conforms to the future development of neighborhoods. It takes practice to test.

Table 5 Weight values of sustainable development Indicators of green blocks

First Grade Indicator	Second Grade Indicator	Third Grade Indicator	Explanation	Weight Value
Economy	Economic level	Per capital GDP		0.007271182
		urban per capita disposable income		0.012226902
		Engel's Coefficient	Food spending accounts for the proportion of the total amount of personal consumption expenditure	0.002496195
		Housing balance index of employment	Residents in the local employment of employment population proportion	0.004198741
	Combined indicator of Economic level			0.02619302
	Format layout	Commercial business index	Commercial business building area of public construction area proportion	0.005190154
		Functional forms mixed index	Length of unit length of commercial shop along the street number, street number of types of architectural forms, unit number of blocks within the main forms	0.010381866
	Combined indicator of forms layout			0.01557202
	Circular Economy	Utilization of renewable energy	Clean energy consumption value/total energy consumption	0.035605226
		Utilization of water of life		0.012226902
		Rainwater utilization		0.007269019
		Waste recycling rate		0.021173973
	Combined indicator of Circular Economy			0.07627512
	energy utilization	Energy self-sufficiency rate		0.010940793
		Energy consumption per unit of GDP		0.004717423
		Water consumption per unit of GDP		0.00723943

© ASCE 2014

		Emissions per unit of GDP		0.001397083
		Garbage output per capita		0.002036657
		Daily water consumption per capita		0.003075397
		Sustainable energy utilization ratio		0.015953056
	Combined indicator of energy utilization			0.04535984
Combined indicator of Economy				0.1634
Society	Road Traffic	Car share		0.011426624
		Roads scale	The average number lane road	0.003702034
		Slow channel coefficient	slow channel length/ Total length of block road	0.005240541
		Transport Accessibility		0.007676511
		Road density		0.037164572
		Intersection density		0.0254014
		Traffic Safety		0.017067818
		The proportion of green travel		0.052565674
	Combined indicator of Road Traffic			0.160245174
	Public Service	Mixed land use		0.007750096
		free style facilities worldwide residential area ratio around 500 m on foot		0.017078376
		Barrier-free facilities coverage		0.003292334
		The pollution-free food share		0.001495633
		Education index	Primary and secondary attendance rates	0.011712551
		Cultural diversity index		0.005050188
		Theft rate		0.002180322
	Combined indicator of Public Service			0.0485595
	Infrastructure	Municipal pipe network penetration		0.014131082
		Hazard-free treatment rate of household garbage		0.023234251
		Integration of Three Networks rate	TV Phone Internet	0.005424854
		Smart home network system coverage		0.008600378
		Waste collection index		0.036809616
	Combined indicator of Infrastructure			0.088200179
Combined indicator of Society				0.297004853
Environment	The natural environment quality	Air quality rate		0.132945051
		Surface Water Quality		0.083751856
		Native plants Index		0.035163185
	Combined indicator of natural environment quality			0.251860091

© ASCE 2014

	Space environment quality	Building density		0.030421304
		Building height		0.005864556
		Blocks two dimensions		0.00899578
		Volume rate		0.013805062
		Average building layers		0.002664135
		Architectural street aspect ratio		0.020863289
		Streets interface density		0.003883755
	Combined indicator of Space environment quality			0.08649788
	Artificial Environmental Quality	The proportion of green building		0.024296418
		The proportion of using local building materials	Using local materials building total proportion of the number of buildings	0.00468852
		The proportion of public green		0.033239058
		Per capita public green		0.053521025
		Large tree density	Tree/ha	0.006830559
		Blocks inside greenbelt rate		0.015833116
		Building three-dimensional green ratio		0.011399244
		Night lighting energy saving green light accounting		0.034284301
		Seepage paving materials share		0.017139579
	Combined indicator of Artificial Environmental Quality			0.201231819
Combined indicator of Environment				0.539589791

4.4 The Implementation Strategies for Sustainable Development Indicators in Green Blocks

Implementation strategy of indicators is formulated by the concrete content of sustainable development indicator of green blocks. In the development process of building blocks, planning strategies can be formed from the economic, social, environmental dimensions, which can provide protection for the indicator system to set a management system.

The implementation strategies of sustainable development indicator system of green blocks include the following:

(1) The sustainability of green blocks' indicator system should be focused. In order to achieve sustainability, Indicator's splitting and refinement should be goal-oriented and need a long term planning according to the realities of blocks.

- (2) The effectiveness of the indicator system of green blocks should be focused. The core indicators should be seriously concerned, and we should pay attention to the implementation of

© ASCE 2014

indicators rather than the number of indicators. Meanwhile, to develop a certain implementation and operational methods and strategies is equally important.

(3) In the green blocks indicator system construction, focus on the use of traditional planning and design methods and development of new technologies and materials are also essentially important. Through the effective combination of them, technical support could be effectively formed.

(4) Management system of green blocks' indicator system, including GIS-based platform management system and the necessary laws and regulations, rewards and punishment mechanisms should be developed.

(5) It is very important to pay attention on public participation and oversight mechanisms. In order to assess the economic costs, resource utilization, the contribution to environment during the implementation process, hearings and public seminars should be organized in communities. Accordingly, it is possible to make adjustments on implementation strategies and indicators.

4.5 The Evaluation and Correction of Sustainable Development Indicators of Green Blocks

According to the concrete Contents of green blocks' indicator system, the method which combined with comprehensive indicator evaluation and individual indicator evaluation can be used. In general, comprehensive indicator evaluation is more complex, which could employ the Driving force - Pressure - State - impact - response frame model (DPSIR). It combines the specific requirements of green blocks, indicator system evaluation method and virtuous indicators evaluation feedback mechanism and generally includes about four steps: (1) establishment of DPSIR framework to identify requires a combination of the main indicators of evaluation methods; (2) indicator to select and weight division; (3) applying indicators evaluation methods to analyze the result; (4) compared to other auxiliary indicator evaluation methods; (5) indicator correction;

Individual indicator evaluation can combine with the above evaluation methods to adopt a simpler analytical model to consider and evaluate. Combining AHP, a Sweden research project entitled "Sustainable Urban Water Management" established a sustainable indicator analysis and evaluation model to determine the practicable, sustainable, concise, quantifiable and strongly connected indicators

5. Conclusion

In summary, from the perspective of urban planning, this paper analyzes the research status of Chinese eco-city indicator systems, attempts to explore the formation mechanism for the indicator in green blocks, and puts forward reasonable proposals for choosing the pointer element, the specific content, implementation strategy, the pointer evaluation and correction, etc. The

© ASCE 2014

paper also meets the current needs in the process of construction of ecological cities in China and has a positive significance on improving the sustainability indicators system of Chinese eco-city green blocks.

© ASCE 2014

Urban Ecological Infrastructure: Challenges, Construction and Management

Feng Li and Rusong Wang

State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China；PH ＋86-10-62849103; FAX 86-10-62849103; email: lifeng@rcees.ac.cn, wangrs@rcees.ac.cn

ABSTRACT

Urban is a typical social-economical-natural complex ecosystem dominated by human activities. Rapid urbanization brought a wide array of entwined and intricate ecological and environmental problems. Traditional urban infrastructure fails to deal with current urban environmental problems. In this paper we suggested the concept of urban ecological infrastructure based on analysis and induction of the urban environmental problems and its origins. We identified and compared the logic hypothesis of the related concepts on urban ecological infrastructure. Urban ecological infrastructure refers to the engineering facilities that can provide basic ecological services for urban production and consumption activities. It is a kind of public service system to ensure the sustainable development of physical and social ecological process including physical eco- infrastructure and social eco-infrastructure. At last the construction and management of ecological infrastructure were discussed.

Key words：Urban ecological infrastructure; New urbanization; Ecological services

1. The ecological challenges of new urbanization

The multicolor ecological effects of urbanization: Rapid urbanization generated a wide array of ecological and environmental effects which would be summarized as the followings and be represented by its color for the sake of vividness: urban heat island effect (red), water bloom effect (green), dust-haze effect (grey), traffic jam effect (yellow), bald spot effect (white), and garbage besieging city effect (motley). In particular, the dust-haze, traffic jam, water pollution, and garbage effects have severely threatened the physical and psychological health of urban population, and have become hot issues and serious social concerns. Together with global climatic change, regional ecological degradation, and urban ecological health, they have all been political concerns pertaining to national security and social stability.

Symptoms of urban infrastructure: Urban infrastructure include water supply and drainage (point source) and purification (area source) ; regional energy supply and photo-thermal dissipation systems (heat island); urban construction land and soil ecological vitality (geo-gas); urban vegetative landscape and biodiversity networks (entelechy); urban resource supply and venous industry (garbage); atmospheric flow field and substrate ecological patterns (dust-haze); high-carbon transportation networks and low-carbon quality of life (traffic jam).

Urban symptoms: If we assimilate a city to human body, the urban wetland can be referred as kidney because the water purification and water storage/drainage function of wetland are similar to human's kidney. Accordingly we can draw similar analogy between urban forest and lung, building/road surface and skin, urban metabolism and digestive system, road network,

© ASCE 2014

waterway, air-duct and vasoganglion. The current critical problems of urban ecological infrastructures in China are: kidney failure (urban wetland degradation, watercourse cutoff, water pollution, and frequent floods); lung weakness (mono-structure of urban vegetation , biodiversity loss, and unreasonable spatial pattern); skin inactivation (urban soil sealing, soil degradation, and grey roofs); digestive functions disorder (pollution discharge, decentralized processing of nitrogen and phosphorus, and inability of eco-regulation); aortic blockages (landscape fragmentation, traffic jam, and Feng-shui disorders).

The ecological origins of urban problems: The root causes of the above urban problems can be summarized as three aspects: 1) the retention and exhaustion of material metabolism at spatial-temporal scales (materials); 2) the fragmentation and rigidity of the system structures and functions (process) ; 3) the segmentation of social institutions and failure of information feedbacks in urban planning and management; the shortsighted human behavior dealing with holistic and local, long-term and short-term interests (man).

Urban environmental problems are a series of entwined and intricate social-economic-natural complex ecosystem issues. The exclusion of ecological land in urban planning, the highly fragmented and segmented management system, the lack of ecological infrastructure in urban construction, the idea of treatment after pollution, priority and excessive emphasis on economy scale, environmental assessment after construction, the traditional environmental engineering guided by reductionism in urban research, all the above problems, led to the knotty urban problems. Due to such historical accounts and the fact that the whole country is transferring from the initial stage of industrialization to its intermediate stage, the above mentioned environmental problems cannot be solved immediately. Yet as the first step, we can start from ecological planning, ecological engineering, and ecological management to reorganize, restore, and construct urban ecological infrastructure.

2. Shifting from municipal facilities, green infrastructure to ecological infrastructure

The evolution of ecological infrastructure: shifting from light green, grey black, variegated green to dark green. Natural circulation infrastructure (light green): return garbage to the farmland, wastes recycling. Municipal infrastructure (grey black): flood drainage, wastewater treatment, garbage treatment, roads and transportation system. Environmental infrastructure (variegated green): planted vegetation, water and energy savings, photo-thermal facilities. Ecological infrastructure (dark green): technology integration of kidney-lung-artery-skin-anus and complex ecosystems.

Municipal infrastructure adopted physical methods to deal with the urban environment, and simply send the untreated or undertreated pollutants out of an urban area. Green infrastructure adopted physicochemical, biological, and environmental engineering methods to treat wastewater and to turn grey cities to green cities. Ecological infrastructures adopted ecological engineering methods to planning, designing, constructing, and managing ecological facilities, which showed the eco-vitality of self-organization and self-regulation. Ecological infrastructure realized the purification, beautifying, activation, and sustainable evolution of urban ecological processes. Ecological infrastructure also realized pollutants treatment and regeneration in an

© ASCE 2014

urban area without harming rural environment, thus resulting in the co-evolution of both urban and rural environment.

Hypotheses for municipal infrastructure: Municipal infrastructure send the untreated and under-treated pollutants to rural area. This practice is only justified Aunder a false hypotheses that the environmental capacity in rural areas is unlimited and rural area could absorb all the pollutants from the urban area. There will be a steady flow of water resources from upstream, and there is no need for groundwater recharge. Urban soil sealing helps to make urban environment cleaner, the clean-up of ruderals makes urban environment more beautiful. The ring road networks are more efficient than ribbon pattern road networks. Exhaust gas can be diluted by wind and chimney stacks.

Hypotheses for green infrastructure: Sufficient amount of urban green spaces, wastewater, garbage, and wasted gas treatment facilities can solve urban environmental problems. The key issues to solve urban environmental problems are enough environmental investment and high-tech environmental protection techniques provided by both the government and enterprises. As long as the city government constructed and managed their individual infrastructure sub-systems well, the city itself will become clean, green and beautiful.

Hypotheses for urban ecological infrastructure: The current urban-rural environmental problems are in fact a kind of ecosystem syndrome, not a simplistic causal relationship that were caused by inappropriate human activities in urban areas. The systematic and engineering integration, the ecological management of urban ecological factors (water - soil- air - biology - mine) and ecological processes (production - circulation - consumption - reduction - regulation), the ecological mechanism of self-organization, self-adaptation, and self-coordination, and the ecological consciousness of planners, decision makers, managers, and citizens are vital to strengthen the vitality and the evolution of urban ecosystems. The primary goals of urban management are the activation and sustainable evolution of urban ecosystems.

3. The structure and function of urban ecological infrastructure

The concept of urban ecological infrastructure: The engineering facilities that can provide basic ecological services for urban production and consumption activities. It is a kind of public service system to ensure the sustainable development of physical and social ecological process. It includes physical eco- infrastructure and social eco-infrastructure. Discussed here is only physical ecological infrastructure. It includes Kidney, Lung, Artery, Skin and Anus (KLASA), related to water, biome, energy/air, soil and minerals respectively. Purified and vitalized urban wetland such as river, lake, ponds, and marsh (Kidney); Diversified and rich urban nature, park, garden, animal, microorganism and agro-forestry (Lung); Natural and Unobstructed urban corridor, Feng-shui and main avenue (Artery), Permeable and livable urban surface, building roof, river bank and road (Skin); Ecologically sound urban wastes discharging, buffering, reduction and regeneration exits (Anus), and their integration in urban ecosystem scale.

Ecological Infrastructure of Industrial Park: eco-hydrology (sewage treatment, rainwater, cleaning drainage, ecological living water); ecological energy (solar energy, clean energy use, waste heat utilization, natural ventilation, warmth, cooling); ecological metabolism (life cycle

© ASCE 2014

design, ecological process, venous industry, zero waste emissions); ecological park (plant, landscape, surface, roofs, roads, biological); natural ecosystems (water, road, air, noise, ecosystems); social ecology (living facilities, resources, ecological , market ecology, the surrounding communities).

Rural ecological infrastructure: eco-hydrological systems (safe potable water, rainwater collection , cleaning drainage, zero energy water, ecological living water); ecological energy (solar, biogas, wind energy, biomass energy); ecological sanitation (manure, waste, compost, Village); ecological architecture (shape, structure, materials, facilities, pattern); ecological landscape (Feng-shui forest, courtyard, ponds, roads, surface); ecological humanities (context, religion, education, medical, sports).

Urban social ecological infrastructure: Urban social ecological infrastructure involves residence, traveling, education, entertainment, shopping and so on for human beings. However currently the rural areas are lack of the basic ecological service facilities for sports, spirit, employment, communication, wisdom.

4. The construction and management of urban ecological infrastructure

The goals of Urban ecological infrastructure: cleaning (clean, quiet, health, safety), green (landscape, industrial, behavior, mechanisms), activation (water flowed, wind unblocked, soil fertilized, life flourished), landscaping (context, texture, and material state of mind), evolution (material balance, entropy reduction, biodiversity, harmonic).

Measurement indicators for functions of urban ecological infrastructure

(1) Occupation of natural water resource: It refers to the water quantity (including the footprint of upstream and downstream) urban production occupied by production process in the target area it also include the ecosystem services (including the footprint of upstream and downstream) which is occupied by the process of producing such amount of water.

(2) Rate of ecological land: refers to the area proportion of open space and building surface area for providing ecological services, such as soil conservation, the hydrological cycle, climate regulation in the target area (or built-up area, or cell) and the total covering area should be ideally close to or more than 100%;

(3) Rate of ecological energy utilization: the actual utilization ratio of waste heat, geothermal, solar, wind and biomass and other renewable energy sources which can be utilized in the target region;

(4) Biodiversity: the diversity, richness, evenness of the greenbelt and landscape quality of a local area;

(5) Rate of ecological metabolic cycle: the ratio of recycled waste material in urban metabolism, the rate of products with life cycle design, the ratio of management based on life cycle assessment in an industry and or an industry park.

Strengthening the construction of institution and mechanism system

© ASCE 2014

Urban ecological infrastructure is the core of urban ecological construction and the characterization of urban ecological quality. At present, we need to strengthen the construction of urban ecological infrastructure from the aspects such as updating traditional concept on urban infrastructures, system innovation and technological innovation including countermeasures for the planning and management:

(1) The management regulations of regional and urban ecological infrastructure planning.

(2) Promotion of the detailed regulatory planning of the urban ecological land.

(3) Compensation on-spot, synchronous restoration and online regulation for occupation of ecological land.

(4) Property management and industry incubation of urban ecological assets.

(5) Integrated management of the urban household garbage reduction, innocuousness, recycling, industrialization and socialization in the whole process.

(6) Construction, renovation, management and assessment methods for urban natural ecological infrastructure (kidney - lung - skin - anus - artery).

(7) Construction and management of rural natural ecological infrastructure (hydrology - energy - garbage - sanitation - courtyard).

(8) Life cycle assessment of enterprise chemicals, design and ecological footprint supervision.

(9) Life cycle management and the responsibility system for full reclamation of enterprise packaging waste.

(10) Regional, urban and industrial decision-making, planning and environmental lifelong accountability system of environmental impact assessment.

References

Wang, R. S., Li, F., Han, B. L., Huang, H. P., Yin, K. “Urban eco-complex and eco-space management.” *Acta Ecologica Sinica*, 2014, 34(1): 1-11(in Chinese).

Li, F., Wang, R. S., Zhao, D. (2014). “Urban ecological infrastructure based on ecosystem services: status, problems and perspectives.” *Acta Ecologica Sinica*, 2014, 34(1): 190-200 (in Chinese).

© ASCE 2014

Mountain Lake Embankment Slope Stabilization by Vertical Vibrated Stone Columns, Highway 1-San Francisco Bay Area

Mahmood Momenzadeh, PE, GE, Senior Eng.,[1] Tung Nguyen, PE,[2]
Matthew Gaffney CEG,[3] Tim Pokrywka, PE, Office Chief[4]

[1,2,3,4]Geotechnical Design West, Caltrans, 111 Grand Avenue, Oakland, Ca, 94612,emails: Mahmood_Momenzadeh@dot.ca.gov,Tung_Nguyen@dot.ca.gov, Matthew_Gaffney@dot.ca.gov, Tim_Pokrywka@dot.ca.gov

ABSTRACT

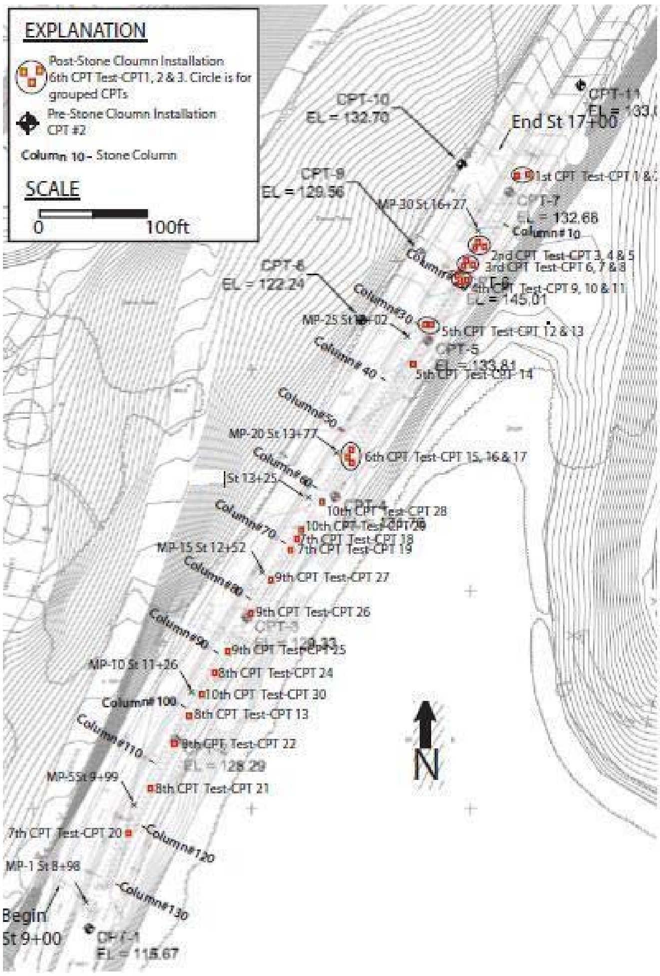
The objective of this project was to enhance the lake sustainability by dredging the lake bottom sediments transported by surface run off and improve the drainage facilities of the adjacent areas to collect the run off. Compacted stone columns (SC) were installed within the shoulder of State Highway 1 adjacent to Mountain Lake in the City of San Francisco. The purpose of the ground mitigation was to densify the subsurface soils below the roadway shoulder and stabilize the western slope of the lake during the dredging as well as for long term seismic ground motion. This paper presents the experiences gained from the design and construction of this project. This method was selected over the conventional structural and other ground mitigations involving cements or other chemically processed construction material to preserve the lake natural environments. The SCs were placed in holes formed by a self penetrating vertically vibrating probe of a heavy steel casing into the ground through bottom feed. The impact of the installation was controlled through monitoring the ground movements by telltales installed along the edge of the adjacent road and ground vibration by seismographs. The subsurface soils densification around the SCs was evaluated through Cone Penetration Testing (CPT) performed before and after the SC installations. A total of 393 SCs were installed to depths varying between 12 ft to in excess of 40 ft successfully. Ground settlements in range of 0.1 to 7.2 inches and vibration with sum peak particle velocity (PPV) from 0.1 to in excess of 1.35 in/sec were recorded during the SC installation causing hairline cracks and minor faulting on the adjacent roadway. This project demonstrates that geotechnical engineering practice has knowledge and tools to help design and construct sustainable civil projects.

INTRODUCTION

Mountain Lake is one of the few natural lakes within the San Francisco County. In 1938 a major area of the northwest portion of the lake was filled during the construction of the adjacent McArthur Tunnel and the existing Highway 1 within the Park Presidio reducing the lake area by about 40 percent. As shown in Figure 1, at approximate Station 13+25, there is an ancient channel that consists of loose sands overlying soft to stiff clay to depth in excess of 45 ft. The lake depth has been reduced

© ASCE 2014

substantially over time due to the sediments transported to the lake bottom by surface run off from adjacent roadways and Park Presidio areas. One of important factors that affect any lake sustainability is accumulation of the sediments transported to the lake bottom due to improper use of the adjacent facilities, lands, and or slope erosions. The sediments are often polluted, causing unfavorable biological change in the ecology of the lake and promoting invasive vegetation's growth which, if not mitigated, will eventually lead to depletion of the lake. The lake sustainability was of prime concern to both Presidio Trust and California Department of Transportation. The lake mitigation program developed by Presidio Trust consisted of dredging the lake bottom by near vertical cuts varying in total height up to 8 ft below the lake bottom to remove some of the lakebed sediments combined with drainage improvements to collect and discharge the roadway run off (PSC Associates Inc., August 1990).



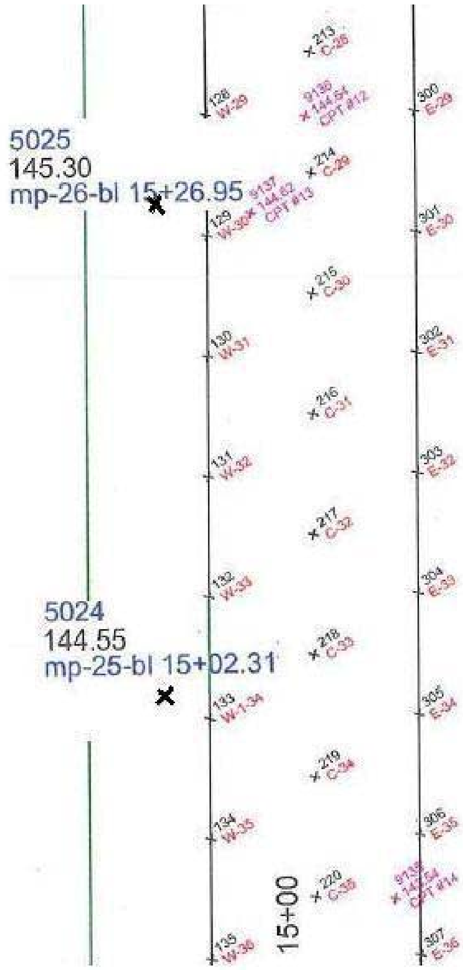


Figure 1. Cone penetration tests plan. Figure 2. Stone columns layout.

Caltrans was responsible for preserving the stability of the Highway 1 embankment slope adjacent to the lake during the dredging as well as for long term seismic condition, drainage improvements and funding both the lakebed dredging and handling of the dredged material. Dredging was done by suction techniques. From the

© ASCE 2014

lake, the dredged material was hard piped to a processing system where it separated the water and sludge. The dredging spoils were 90% water and 10% solids. The spoils were diverted to porous bags then to baker tanks to separate the water from the solids by settlement. The water was treated and pumped back to the lake. Chemicals were added to the solids for treatment and allowed to dry. Samples were taken for soil classification, hazardous material analysis, and moisture content tests. Moisture tests were conducted to avoid off hauling wet material. The solids were off hauled to either Half Moon Bay Landfill or a Class 1 landfill such as Button Willow, depending on the analytical classifications.

Based on the documented damages caused by 1989 Loma Prieta Earthquake and an investigation consisting of 11 Cone Penetration Testing (CPTs) and 3 drilled boreholes conducted in this project within the mitigation project limits as shown in Figure 1, Highway 1 embankment in this area is underlain by fill consisting of layers of loose to very loose to medium dense sands, silty sand, and silt which are inter-layered with soft to firm clay and clay with sand (Caltrans Geotechnical Design West, Branch C, 2012).

The thickness of the fill varies from 12 ft near the south end of project, Station 9+00 to in excess of 40 ft near the north end of the project, Station 17+00 (See Figure 1).

GROUND MITIGATION SCREENING

As shown in Figures 3 and 4, our analyses of the slope stability with the proposed dredging configurations indicated the slope would be unstable, impacting the integrity of the adjacent Highway 1, which is one of the only traffic routes in the project area to the Golden Gate Bridge. In addition, the site is located within a high seismic area due to a distance of less than 5 miles to the San Andreas Fault, generating a maximum magnitude of 7.9 with Peak Ground Acceleration of 0.59 g (g: gravitation acceleration). The liquefaction analyses of the embankment slopes conducted for the seismic performance of the site indicated high liquefaction potential of the loose and medium dense sand, sandy silt and low plastic silty soils of the road embankment in an event of the design earthquake. The drop of 2 ft of the roadway embankment observed in the 1989 Loma Prieta Earthquake in this area is associated with the liquefaction consequences of the loose sandy material present at this site.

Various types of the embedded retaining walls such as soldier beams with or without tiebacks (Momenzadeh et al., 2001 and 2004) and clustered micropile system (Momenzadeh et al., 2012) as well as ground mitigation alternatives including soil cement deep mixing, grout injection, jet grouting which have been used by Caltrans for other projects were considered to provide primarily slope stability during the lake dredging and long term seismic stability of the highway embankment slope. These methods were screened in context of their environment, economics, and social performance which are paradigms of a sustainable development. Screening of these other methods indicated that they adversely impacted the lake environment and its long term sustainability because they not only involve use of construction materials and methods that disrupt the current lake environment by producing dust and noise, but also introduce materials that either corrode overtime, introduce chemicals, or are incompatible with the ecology of the lake, groundwater and the surrounding environment. Based on thorough research, we determined that the stone columns mitigation method can potentially improve the embankment slope stability, prevent or reduce the liquefaction potential of the subsurface loose soils, and does not impact adversely the lake sustainability which would be enhanced substantially by the proposed dredging.

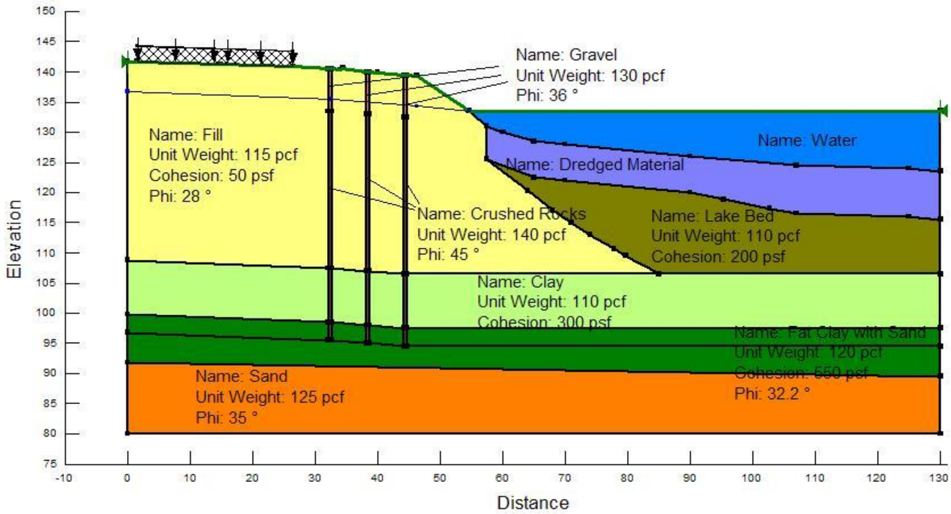


Figure 3. Base slope model showing proposed dredge condition.

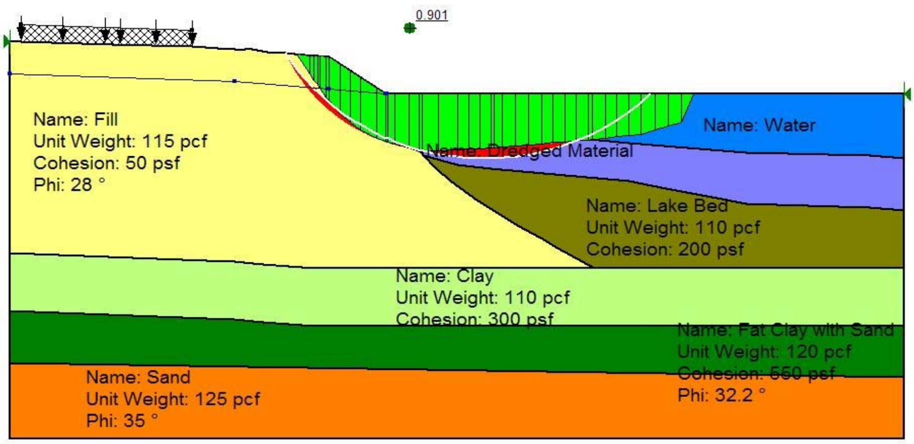


Figure 4. Slope stability without stone columns.

STONE COLUMNS DESIGN

Due to the limited width of the working area of no wider than 17 ft, three rows of the SCs in a triangular grid pattern with a spacing of 6 ft were analyzed and designed to achieve the required ground mitigation. The design concept and procedure were based on FHWA reports (FHWA-RD-83-027, 1985, and AASHTO, Task Force 27 Report,

© ASCE 2014

1992).

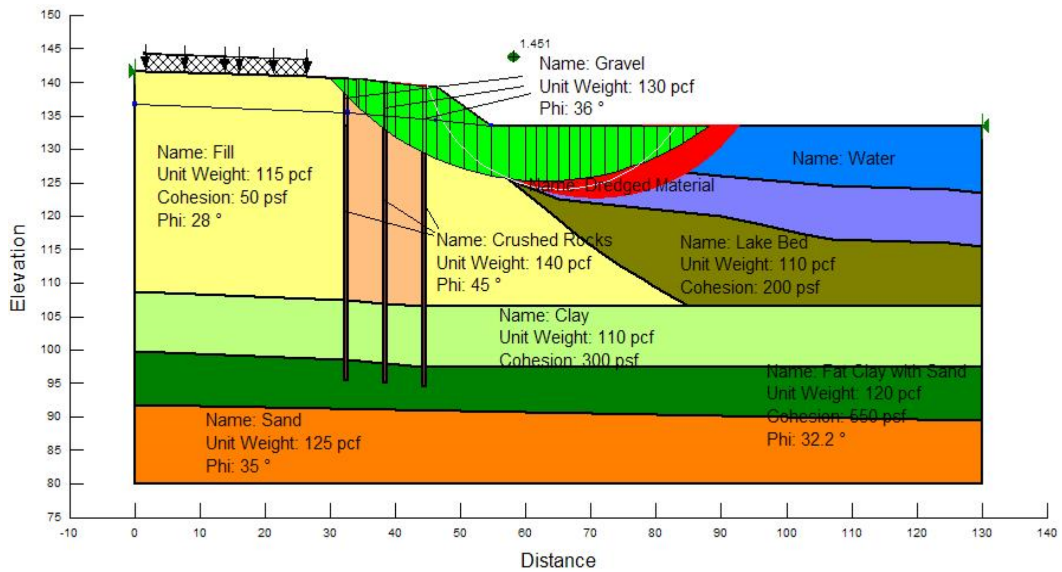


Figure 5. Slope stability with stone columns Note: Elevation and Distance are in Feet

The area replaced with SCs represented by AR (Area Replacement) Ratio was about 10 percent of the total site area. The layout of stone columns is shown in Figures 1 and 2. Figure 2 shows a close up of the SC layout from Stations 14+77 to Station 15+27. Shown on these two figures are also the locations of CPTs before and after SCs, drilled BHs and ground settlement or heave monitoring points (MPs). The densification criteria were to achieve dense SCs (gravel columns) with the loose sandy soil between columns becoming very compact to dense.

Additional slope stability analyses, results of which are shown in Figure 5, demonstrate that the slope will be stable with use of the proposed SCs during the dredging. The seismic stability of the embankment slope and the adjacent roadway were not part of the scope of this project. However, based on some analyses we conducted, it is our opinion that the liquefaction consequences such as settlement and lateral spreading will be significantly reduced by the SCs and the densified soils around it as shown in the subsequent Performance CPTs results.

The next step in our design approach was to determine a compaction method of the stone columns to achieve the density required for the stability of the slope mainly for the dredging conditions. Because of the maximum required densification depth of 40 ft, a vibrating impact stone column installation capable of placing the gravels with a specified gradation at the bottom of hole (bottom-feed) was selected.

STONE COLUMNS CONSTRUCTION

Equipment

SCs were installed using a vertically vibrated probe mounted to a vibratory

© ASCE 2014

attachment on a Bauer RTG 235 Drill Rig. The gravel transfer pipe (casing) was 50 ft in length and 18 inch inside diameter. The rig is equipped with sensors and software to record the SC length, gravel intake volume, and the hydraulic pressure and compression step with the time during a SC installation. The probe tip was about 21 inch in outside diameter. Support equipment included a small loader with side dump bucket of about 3 cubic yard capacity and a drill rig to pre-drill a hole of 2 ft in diameter to about 7 ft depth before a SC is installed.

The gravel used was ¾ inch minus (20 mm) with less than 5 percent fines (passing #200-sieve). A picture of the gravel used is shown in Figure 9.

Installation

The probe penetration into the soil formation was achieved by vibrating a very heavy duty hollow steel cylinder of 18 inch outer diameter which sunk into the ground to the specified tip elevation followed by inserting the gravels into the hole and compacting the gravels. The compaction of the gravels was achieved by a short plunge and pull strokes of the vibrating steel cylinder while it is gradually withdrawn from the hole.

In order to reduce the vibration caused damages to the adjacent roadway and ground heave normally associated with the stone columns construction, it was also planned to start SC installation from the roadway and progress toward the embankment slope to reduce the vibration impact and heave more by free slope face movements.

Figure 6. General view of construction site.

Figure 7. Loading gravel.

Figures 6 through 9 were taken during the construction. The observed cracks at the edge of travel are shown in Figure 8.

Ground Densification and Verification

The densification of the embankment was achieved through the combined compacted SCs installed and the densification of the surrounding soils by the vibration propagated through them during the SC installations. Figure 10 shows typical CPTs Tip Bearing (Qt) and the interpreted Standard Penetration Test (SPT) values recorded prior and after SC Installations (See also Figure 1 for all CPT locations). As shown in this Figure, Qt increases by a factor ranging from 3.0 to 4.5 and more locally in thicker uniform sandy soil. Similar results indicate increase in Qt from 2 to 3.0 in the mixed soil layers of silt, sandy sit and silty sand. The densification in the clayey and silty clayey soils was insignificant.

Figure 8. Pavement cracks. Figure 9. Gravel pile at the end of probe withdrawal.

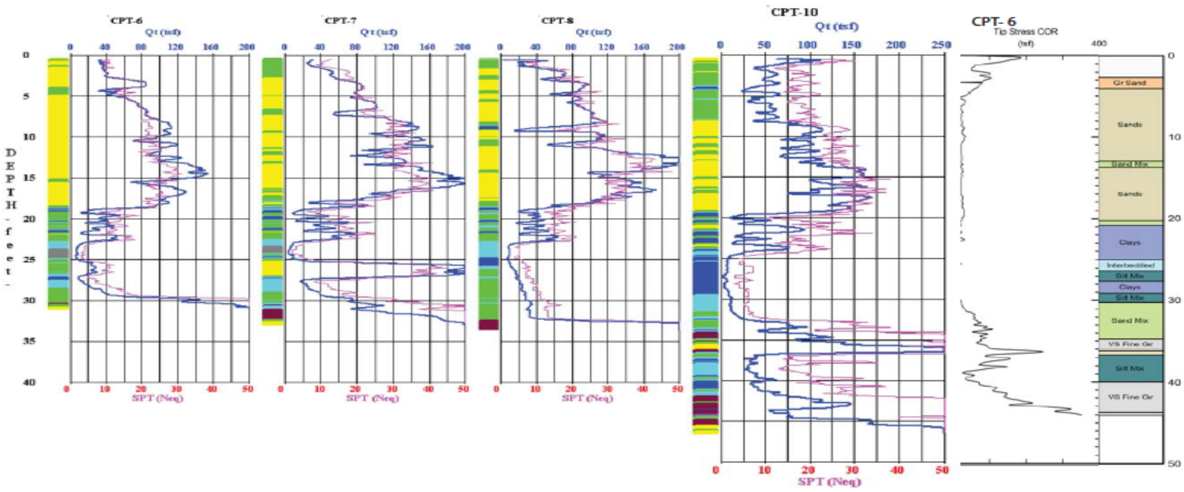


Figure 10. Post construction CPTs 6, 7, 8 and 10 data vs. prior CPT 6.

Figure 11 shows the plots of SC embedment depth, actual gravel volume, and the estimated gravel volume for all SCs. The SCs labeling starting with E, C, and W refer to the eastern, central, and western columns, respectively at any column location. In order to fit the estimated loose gravel volumes with the actual volumes placed in the columns, an enlarged hole diameter of 24-inch and a gravel volume reduction factor of 20 percent, due to the densification, were used. As shown in Figure 11, the variation in the SC embedment depths is generally consistent with those in estimated and actual gravel volumes. However, as shown in this figure, the intake gravel volume for some columns was higher than that estimated due to excessive soil caving caused by increased vibration levels to penetrate through obstacles encountered and hole enlargement more than that assumed. Also, it was observed that effect of vibration on the densification of gravel appear to be less for shallower holes since a larger section of the vibrating casing is out of the ground. This deficiency could be mitigated if smaller length probe is used for shallower SC.

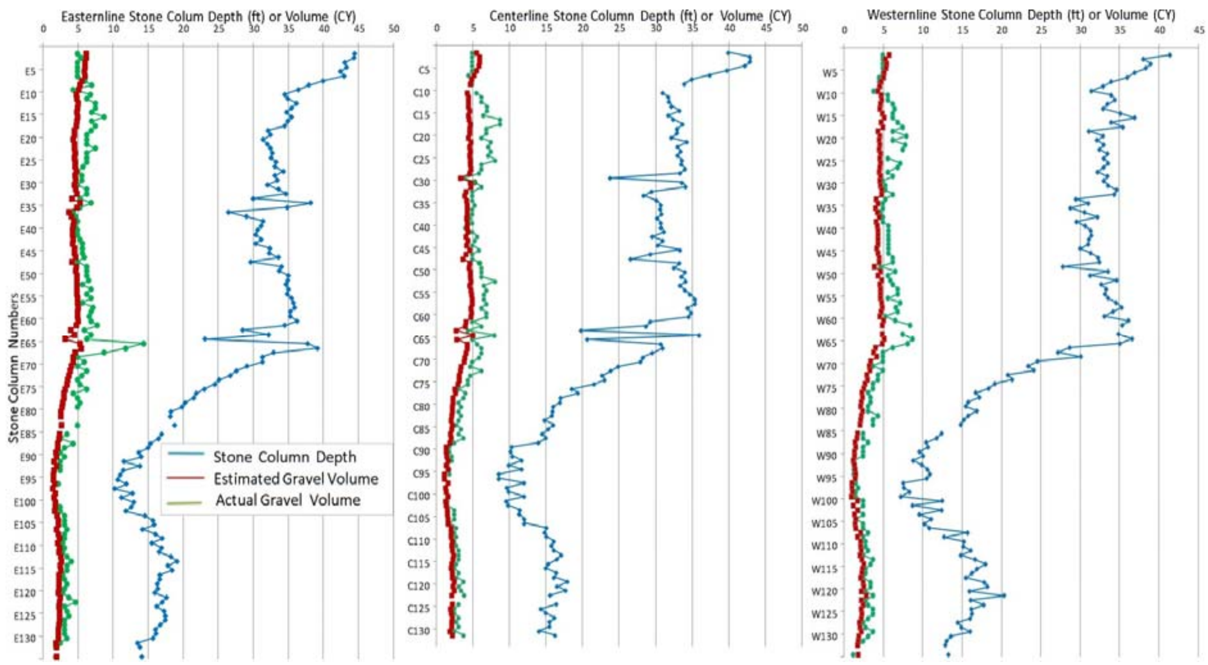


Figure 11. Depth and estimated and actual gravel volumes for all stone columns.

Ground Monitoring

The closure of the adjacent Highway 1 for the construction was not allowed. The challenge was to install these columns within a narrow available corridor, which was no more than 17 ft wide without causing traffic interruption and major damages to both the adjacent roadway pavement and the lake side slopes due to the ground vibration caused during the operation. Since the offset of these facilities from the column locations were insufficient to prevent the anticipated damages, it was specified to predrill all SC locations to 7 ft depth, start plunging the steel column from this depth with imparting the vibration and tamp the upper 7 ft of gravel in layers as the probe is withdrawn instead of vibrating it to densify. Extensive ground movement monitoring was conducted by telltales and survey during the operation to control the extent of damages and develop revision in the SC installation, when needed. The locations of telltales marked by "MP #" are shown in Figures 1 and 2. The largest ground settlements profile measured is shown in Figure 12. Vibration monitoring was also conducted at the locations adjacent to the largest measured ground settlement and other adjacent sensitive areas as shown in Figure13.

© ASCE 2014

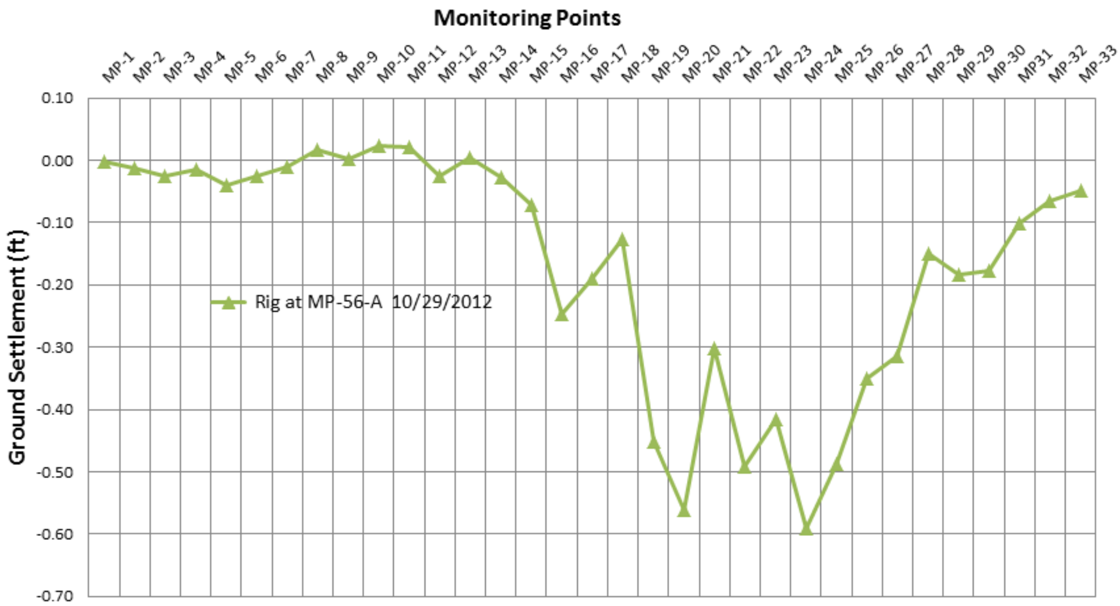


Figure 12. Recorded Max. ground settlement/heave profile at monitoring points.

As shown in Figure 12 up to 7.2 inches of ground settlement was observed within the area of SC 56 to SC 30 (See Figure 1 for SC #) where the SC installation was in progress in vicinity of SC 56. At these locations the sandy soils are about 20 ft, the thickest within the construction corridor.

The 3665 and 3722 seismographs were located near the slope on the eastern and near the edge of travel way on western limits of the SCs area, respectively. Typical plots of three X, Y, and Z components of PPV versus the frequency and vibration time histories are shown in Figure 14. The first and second graphs are PPVs versus vibration frequency for locations 3772 and 3665, respectively. The third graph shows the time history of PPV for three components of longitudinal, transverse, and vertical PPVs for the location 3772. The recorded PPV for other stations were insignificant.

As shown in Figure 14, the PPV sums at two stations of 3772 close to roadway and 3665 close to the slope were typically about 0.6 and 1.35 in/sec, respectively. The PPV magnitude was the highest for the vertical and lowest for the transverse vibration direction as shown in this figure. This data also shows the vibration level was about twice higher near the slope than the roadway side mostly due to the slope free faces. As shown in Figure 8, separation of the PCC slab from the working area and a few hairline cracks on the Asphalt Cement cover on the PCC slabs were developed within the adjacent lane of the Hwy 1 pavement. The longitudinal crack, shown in Figure 8 adjacent to the working area, are results of the ground settlement caused by vibration and the rig weight. However, the hairline cracks on the AC cover were mainly results of the vibration since no settlement was recorded at that area.

© ASCE 2014

Figure 13. Location Map of the vibration monitoring points.

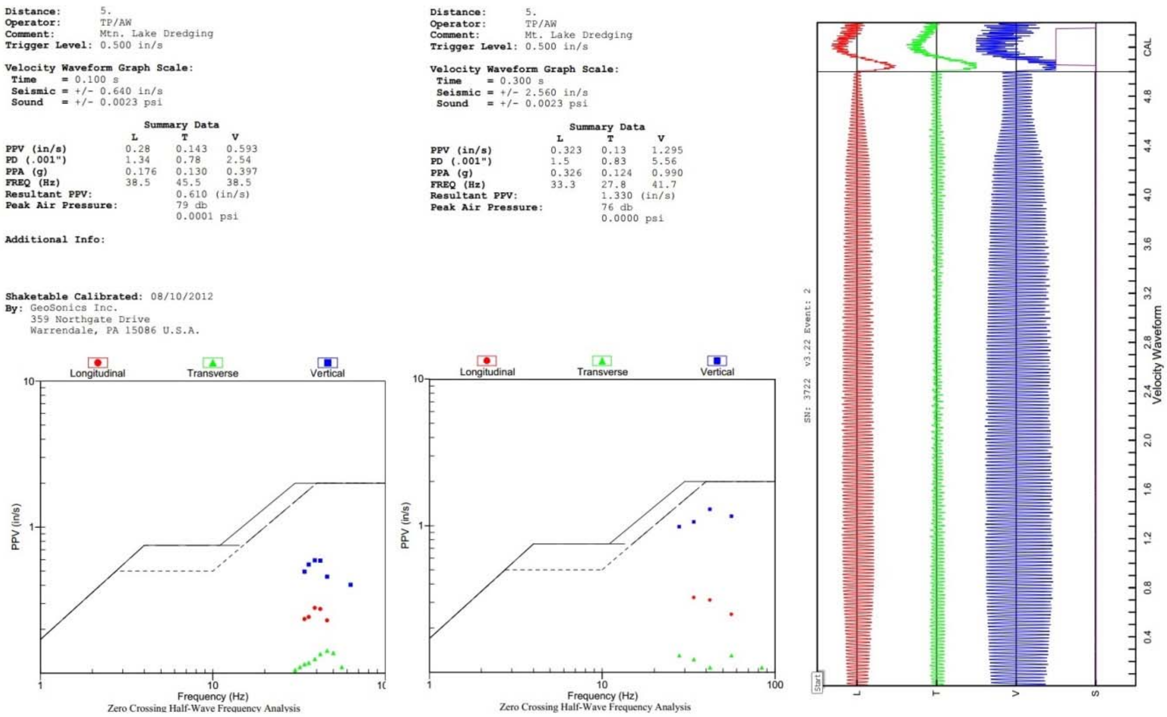


Figure 14. Vibration data for locations 3722 and 3665.

At few instances, a higher level of PPV, about 1.1 in/sec near roadway and 2.1 inch/sec near the slope, was recorded when the probe encountered intermediate denser soil layers before reaching the specified column tips. However, the rates of penetration and

© ASCE 2014

vibration amplitude were lowered to keep the maximum vibration within the typical values mentioned above. This measure combined with pre-drilling mentioned above limited the pavement damages to a shallow depth, which was easily repaired subsequently.

CONCLUSIONS

A total of 393 stone columns were installed through loose to very loose sand and silty sand and lower clayey material into dense soil strata below the loose fill to various depths into the dense sandy layers. This project is a practical example demonstration that geotechnical engineering is capable of developing a sustainable foundation method that satisfies the design and performance criteria.

Below are the experiences gained:

1) The total cost of the project was $3.8 million out of which SCs portion cost was only $800,000, which is very low compared to the other structural or ground mitigation methods, which were in excess of a few million dollars. Yet, the construction method and final product were the most sustainable among all other methods studied.
2) The impact of ground vibration, heave, and settlements resulting from the vertical vibrated SCs installation on the adjacent facilities and suitable mitigation methods shall be considered carefully during the design and in the contract documents.
3) Majority of the factors such as the distance from the construction, type of the facilities, installation methods and soil conditions which affects the level of vibration and settlement impact on adjacent facilities can be evaluated practically prior to the construction.
4) Significant ground movements and vibration levels could be generated as results of this method but they taper off with distances quickly. For this project maximum ground settlement of 7.2 inches and typical sum ground vibration, PPV, of 0.65 inch/sec on the road side and 1.35 inch/sec on the slope side were recorded at about 5 ft distance from the vibrating probe. A portion of ground settlement was attributed to the weight of the rig, which was in excess of 50 tons. In few instances, higher PPV was recoded due to encountering local dense to very dense soil layers.
5) The above impacts were mitigated with use of monitoring and additional measures such as predrilling to a sufficient depth, proper installation order of SCs and changing the penetration rate and vibration level of the probe.
6) Densification of sandy and silty sand material surrounding SCs due to use of vertically vibrated SC installation is up to 4.5 times for very loose to loose sandy material and up to 3.0 times for loose mixed soils of layered silt, sand and silty sand material.
7) Gravels in SC can be densified to dense condition regardless of the surrounding soil type with the suitable vibration amplitude and the installation equipment.
8) The length of vibrating probe shall be in proportion to the desired SC depths as far as possible to achieve effective densification of the SC and surrounding soils.

© ASCE 2014

ACKNOWLEDGMENT

The authors like to acknowledge contribution of Caltrans Construction personnel: John Walter, Ken Kennedy and Design Engineers: Larry Jones and Ms. Amy Chen. We also like to acknowledge the work of the General and Sub Contractors: Gillotti Brothers, Inc. and Drill-Tech. Drilling and Shoring Inc. The success of this project would not have been possible without the work of these people and many others who contributed.

REFERENCES

AASHTO, Task Force 27 Report (1992). "In-Situ Soil Improvement Techniques", FHWA-SA-92-041.

FHWA-RD-83-027 (1985). "Design and Construction of Stone Columns", PB 85-215416/AS.

Caltrans Geotechnical Design West, Branch C (2012). "Geotechnical Design Report for Mountain Lake", a report prepared for the design and construction of the project.

Mahmood Momenzadeh et al. (2001). "Evaluation of a Soldier Pile-Tieback Wall at Carquinez Bridge", 4th International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil dynamics, San Diego, California.

Mahmood Momenzadeh et al. (2004). "Landslide Mitigation on the Sonoma Coast in Northern California", Fifth International Conference on Case Histories in Geotechnical Engineering, New York, NY.

Mahmood Momenzadeh et al. (2013). "Seismic Retrofit of 92/280 I/C Foundation by Micropile Groups, San Francisco Bay Area, California", Seventh International Conference on Case Histories in Geotechnical Engineering, Chicago, Illinois.

PSC Associates Inc. (August 1990). "Abbreviated Material Report for Earthquake Damages in the City and County of San Francisco", 04-SF-1 5.7/7.1, Caltrans District 4.

© ASCE 2014

LCA and Sustainability Assessment for Selecting Deep Foundation System for High-rise Buildings

Rajiv K. Giri[1] and Krishna R. Reddy[2]

[1]Graduate Research Assistant, University of Illinois at Chicago, Department of Civil & Materials Engineering, 842 West Taylor Street, Chicago, IL 60607; PH (312) 996-5165; e-mail: giri2@uic.edu
[2]Professor, University of Illinois at Chicago, Department of Civil & Materials Engineering, 842 West Taylor Street, Chicago, IL 60607; PH (312) 996-4755; FAX (312) 996-2426; e-mail: kreddy@uic.edu

ABSTRACT

This study focuses on selecting the most sustainable foundation system based on life-cycle assessment (LCA) and sustainability assessment of alternate deep foundation systems, specifically piles and caissons, over their design life. Sustainability evaluation of alternate deep foundations is performed using triple bottom line: environmental, economic, and social impacts and by considering various life cycle stages that cover raw material extractions, construction, maintenance, and demolition efforts. For design purposes, subsurface soils, factor of safety against bearing capacity and allowable settlement for both foundations are considered to be the same. Technical designs of both systems are developed based on bearing capacity, both primary and secondary settlements and structural integrity. The LCA is conducted to assess potential environmental impacts, such as global warming, acidification, and smog, associated with the concrete and steel production along with the diesel used for transportation and on-site machinery due to mineral extraction and refining, and required energy inputs for processing. Subsequently, economic evaluation and social impact analyses are performed and the results of analyses are compared. For the site-specific conditions considered, it is concluded that a caisson is more sustainable foundation option than a pile foundation in terms of environmental, economic, and social aspects over its design life.

INTRODUCTION

Deep foundations are invariably recommended for high-rise buildings due to poor subsoil conditions at shallow depth and large column loads. It is common practice to use the two alternative deep foundation systems (caissons and piles) as permanent structures alike. Currently, foundation system decisions are based solely on preference, sound technical design, and cost. The superior solution is not decided on sustainability aspects. Consequently analysis of sustainability is required to ascertain the validity of each individual structure of the two distinct foundation systems. Subjects such as construction, environmental impacts, maintenance and demolition also have to be put under consideration, while keeping in mind the desired lifecycle of 50 years of the structure installment. The problem resides in designing both deep foundation systems, and evaluating which system is more sustainable.

In this study, sustainability assessment was performed for two-alternate deep foundations, namely piles and caissons during various life cycle stages of raw materials excavation, unit manufacturing, transportation emissions, energy needed for foundations, possible in-situ degradation, and recycling of materials. As it is defined, sustainability incorporates the environmental, economic, and social impacts associated with a given geo-structure. But, before any of these can be looked at, deep foundations are to be technically sound and well designed. For comparison purpose, the piles and caisson were subjected to the same conditions. The load applied on both alternative foundations was 1000 Kips, the settlement limit was 1 inch, and the depth at which they were constructed was considered as 55 ft. This was crucial in order to establish the more sustainable option in an unbiased approach.

METHODOLOGY

Subsurface Soil Profile

The project site was considered to be located in General Chicago area. Figure 1 shows the typical subsurface soil profiles found in Chicago region for designing deep foundations.

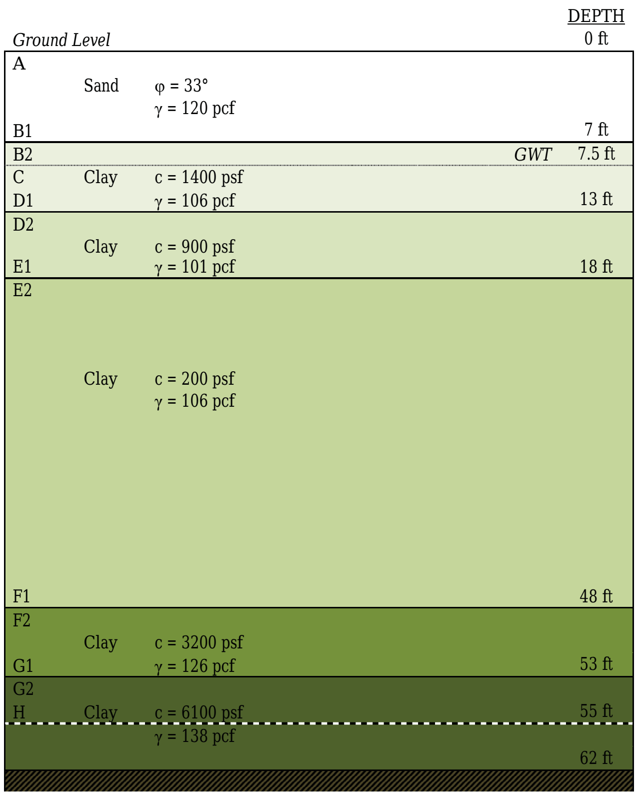


Figure 1. Typical subsurface soil profile considered for two-alternate deep-foundation systems.

© ASCE 2014

The geotechnical engineering properties of soil layers were determined based on literature and the available site boring samples. These properties included the internal friction angle (φ), undrained shear strength (c), cohesion factor (α), and the unit weight of the dry and moist soils (γ). Using these findings, along with the principles for deep foundations design, the pile group and caisson properties were determined.

Technical Design

Technical designs were carried out based on load transfer mechanism by evaluating side frictional resistance and end bearing capacity. Assumptions were made in order to normalize the comparison between the two foundation options. The factor of safety (FS) for both structures was given a value of three. This value is the lowest of the design allowable ranges in order to avoid a conservative design. The same factor of safety was assigned to both alternatives to prevent bringing any discrepancies, therefore increasing quality of the comparison. A dead load of 600 kips and a live load of 400 kips were applied on both alternatives. The idea was to see the behavior and performance for both foundations under especially high loading cases so that the comparison would provide better results. Also, it was assumed that the loading is purely concentric meaning that there will be no moment applied. Therefore eccentricity for both cases was given a value of zero.

The total capacity of piles and the caisson was as a result of skin friction and the toe bearing resistant. Since the coefficients of friction are the same for steel and for concrete, and both foundations are to be the same depth, the size was a key factor for the resistance. A detail step by step procedure of the calculation of the foundation skin friction and tore bearing resistance for both alternatives was based on Coduto (2001). The final design of the piles was a group of 14 pipe piles with an outside diameter of 20 inches and a wall thickness of 0.375 inches. The caisson's final design was a 3 foot diameter shaft with a 4 foot high bell and an 8 foot diameter at the bottom. Both the piles and the caisson had a length of 55 feet. Similarly, the total capacity of 1040 kips and 1020 kips, respectively, was obtained for pile groups and the caisson system. In addition, both foundation alternatives resulted in settlements below one inch, therefore they are satisfactory. No excavation or ground improvement was allowed for this study. This is kept similar to avoid any further confusions and discrepancies. Once the technical design proved to be satisfactory, calculations to determine the amount of materials required were performed (Table 1).

Table 1. Material Assemblies for Foundation Systems in SimaPro.

Foundation Type	Weight (tons)	Distance (miles)	Diesel Fuel (Gallons)		Electricity (MJ)
Piles	27.6	210	Assembly	180	4
			Recycle	269	
Caisson	33.2	30	Assembly	22.1	4
			Recycle	57.7	

© ASCE 2014

For the piles, on the steel for the actual piles was taken into consideration, therefore ignoring the materials required to build the pile cap. For the caisson, concrete and integral reinforcement was taken into consideration. This included the longitudinal and spiral reinforcement to increase the accuracy of the results. A total volume of 124 ft^3 of steel was used for piles construction while the caisson required about 7.8 ft^3 of steel and 462 ft^3 of concrete.

Sustainability Assessment

Sustainability assessment is based on the widely used triple bottom line: environment, economic and social dimensions. When designing any system, any structure or product, careful attention should be given to each step of the design process since each decision made will always have an impact to the environment, economy and the society as well. The main idea is to conduct an assessment on each of the two foundation designs previously mentioned. The environmental impacts of these two designs were studied using SimaPro 8.0.1. The two different scenarios were compared knowing the quantities of materials, energy required for each process and the equipment necessary to complete each mission. SimaPro encompasses various methods to evaluate environmental impacts of a given system; out of which, three methods: TRACI, Eco-Indicator-99, and BEES are commonly used. In this study, the impact assessment was performed using Eco-Indicator-99 method which revolves around environmental damages of three categories: Human Health, Ecosystem Quality, and Resources. Each damage category consists of a number of impact subcategories all measured in kPt (kilo points). This structure facilitates interpretation of the results, allowing analysis of the data separately for each damage category without applying any subjective weighting.

Once the life cycle assessment is determined, economic evaluation of each foundation is carried out using overall system costs (e.g. material & excavation cost, transportation cost, costs associated with drilling/driving, splicing and foundation placing). Thereafter, social aspects regarding both foundation systems were evaluated. In order to achieve this, it was necessary to analyze how both design alternatives would interact with the people and its surroundings. Three main issues were discussed, health and safety, well-being, and satisfaction. For this specific study, only actual foundation was taken into consideration ignoring any building that could be supported by the foundations.

RESULT AND DISCUSSION

Sustainability Assessment

Environmental Sustainability

As mentioned, Eco-Indicator 99 was used to assess the environmental impacts of both foundation systems. Figure 2 shows the environment impact assessment due to various impact categories using Eco-Indicator 99 V2.08 method for both foundation systems. Higher percentage represents more adverse environmental impacts. Based on the Fig.2, it can be seen that how the piles-model is, for the most of the aspects, almost twice as likely to have a negative impact on the environment as the caisson-design. For example, if we look at global warming, we realize that there is a 90% higher damage potential associated with piles as compared to the caissons.

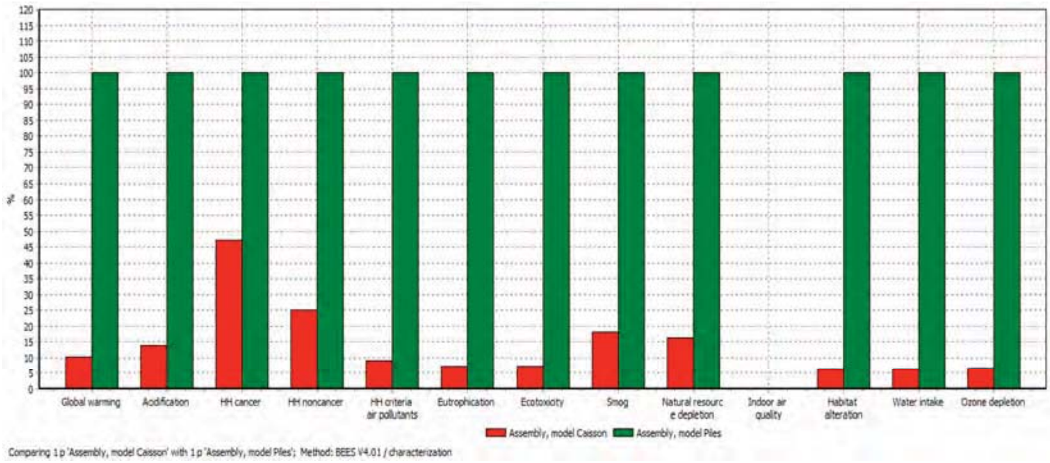


Figure 2. Impact characterization of different variables for selected foundation systems, Eco Indicator

Figure 3 shows the damage potential in three different sections: Human Health, Ecosystem Quality and Resources. It is implied from the result that pile group has a higher damage potential all across the board. For instance, looking closely at the human health section of the graph, we can appreciate that the piles have 5.25 points where as the caissons gets 3.2 points; the higher the points the higher the damage potential. The damage potential for the piles was 40% more than the caisson.

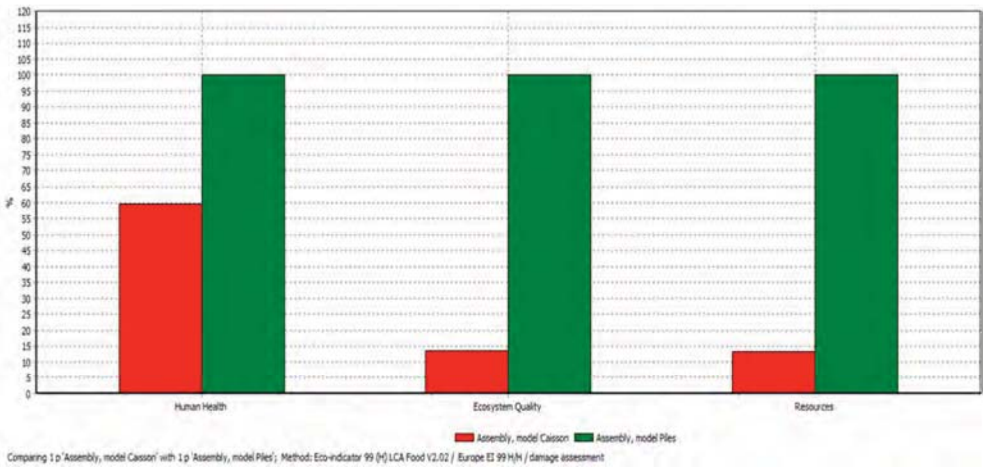


Figure 3. Damage assessment for different foundation systems using Eco-Indicator 99 Method

© ASCE 2014

Similarly, Figure 4 shows the actual energy demand for different foundation systems obtained using Eco-indicator method. It is noted that the energy demand is mainly derived from various environmental impact categories (Fig. 2), such as, climate change, ozone layer, eco-toxicity, acidification and fossil fuels, human health, ecosystem quality and resources. Based on the results, it is cleared that fossil fuel contributed the most to energy demand for both foundations and piles require more energy than the caisson. In addition, it is important to remember that manufacturing steel requires a great deal of energy. Furthermore, shaping the steel piles takes even more mechanical work. As a summary, for the Caisson, about 80 gallons of fuel are needed where as for the Piles about 480 gallons are needed.

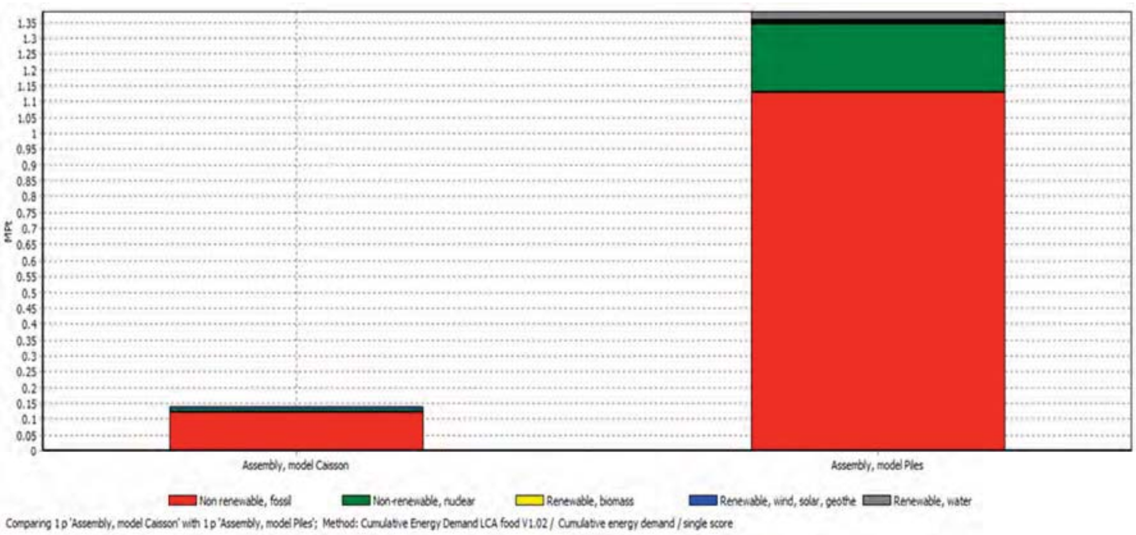


Figure 4. Energy requirements for different foundation systems using Eco-Indicator 99 Method

Figure 5 shows the single score results for two foundation systems as a result of different environmental impact classes. Caisson system scores a value of 1.4 kilo point (kpt) while the piles model scores 4.8 kpt. It is implied that the Caisson system has about a 60% less damage potential than the Piles model. Therefore, we can easily conclude that the Caisson model is definitely a better choice as supposed to the Piles-model if we are concerned with the damage potential to human health, ecosystem quality, and natural resources. Moreover, caisson is more environmentally sustainable than piles.

© ASCE 2014

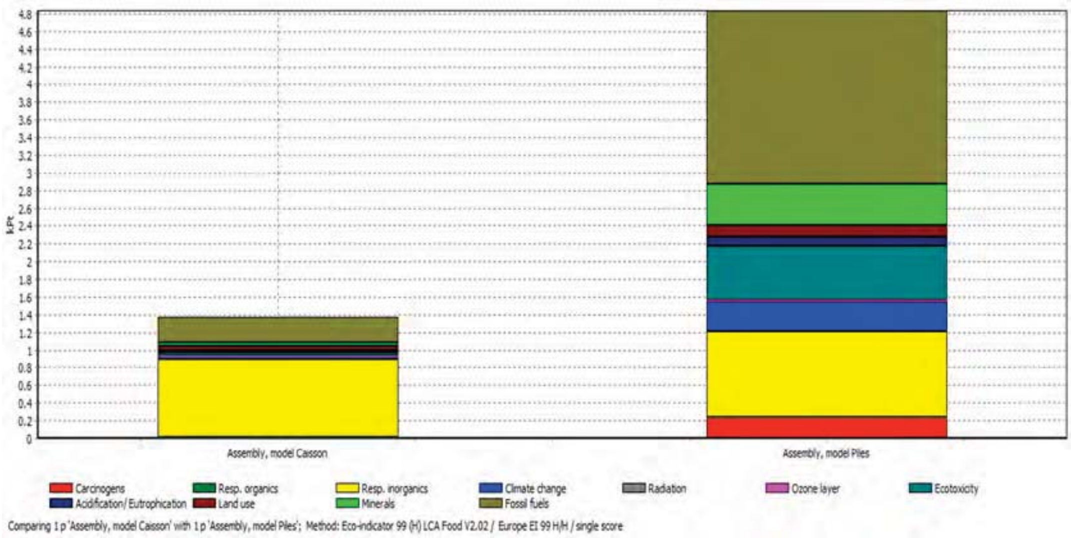


Figure 5. Environmental impact (single score) for different foundation systems

Social Sustainability

First, the issues of health and safety were evaluated using streamlined life cycle assessment (SLCA) health & safety matrix as shown in Figure 6. This evaluates the concerns of physical, chemical, shock, ergonomic, and noise hazards over the entire life cycle of both design alternatives. The life cycle consisted in raw materials excavation, product manufacture, product delivery, construction, field service and disposal of the foundation. Each element of the matrix received a rating ranging from 0 to 4 along with its assigned color code. In other words, the higher the rating, the higher the safety of the design. Due to the fact that there are no clear defined limits on the boundaries of the scale, these assessments were subjective and were based on our own engineering judgment. For example, there is no defined limit between what would be undesirable hazard and tolerable. Comparing the matrixes for each design alternative, it was determined that the caisson produced better results scoring an 82.5% unlike the pile which only scored an 80.3%. The two following tables show the actual matrixes along with its scoring system.

Thereafter, the comfort and well-being was examined. For this the working conditions were considered for both alternatives separately as shown in Figure 7. Another set of matrices were assembled evaluating the diversity, work unions, safety, child labor, community involvement, accessibility, time invested and wages over the life stages of material excavation, product manufacture, construction and disposal. Again, analyzing results showed that the caisson obtained a higher score of 69% unlike the piles which only scored a 65.6% showing that the caisson is a better design alternative.

SLCA Health And Safety Matrix (Caisson)

	Physical Hazard	Chemical Hazard	Shock Hazard	Ergonomic Hazard	Noise Hazard	Row Score
Material Excavation	2.5	3.5	3.8	2	3	14.8
Product Manufacture	3	2	4	2.9	2.5	14.4
Product Delivery	3.5	4	4	3	3	17.5
Installation/ Construction	2	3.8	4	3.5	3	16.3
Field Service	4	4	4	4	4	20
End Of Life	3.5	4	4	3	1.5	16
Column Score	18.5	21.3	23.8	18.4	17	99/120 82.5%

SLCA Health And Safety Matrix (Piles)

	Physical Hazard	Chemical Hazard	Shock Hazard	Ergonomic Hazard	Noise Hazard	Row Score
Material Excavation	2.5	3	3.8	2	3	14.3
Product Manufacture	2	2.5	3.5	2	2	12
Product Delivery	3.5	4	4	3	3	17.5
Installation/ Construction	3.5	4	4	3.9	1.5	16.9
Field Service	4	4	4	4	4	20
End Of Life	3.5	4	4	3.9	1.5	16.9
Column Score	19	21.5	23.3	18.8	15	97/120 80.3%

4 = Acceptable Without Review
3.0 - 2.9 = Acceptable With Review
2.0 - 2.9 = Tolerable
1.0 - 1.9 = Undesirable
0 - 0.9 = Unacceptable

Figure 6. SLCA and Safety Matrix for two-alternate deep foundation systems

Finally, once both design alternatives are implemented, an evaluation of the satisfaction would be the next step. One last matrix was assembled for both design alternatives, which is shown in Table 2. For this, there was a focus on the functionality, maintenance, space occupied, architectural, and service life for both designs. Both designs obtained favorable results in all categories, except piles in the space occupied and architectural issues. This is because the number of piles is too high that it requires a large pile cap to properly transfer the load from the column to the piles. In this case it requires a pile cap of 16.5 ft X 14.66 ft rectangle. With such relative size, it could interfere with the accommodation of other structural members in the building, such as neighboring columns, requiring a modification in the building layout. Therefore, the caisson obtained a higher score in satisfaction.

Working Conditions Matrix (Caisson)

	Material Excavation	Product Manufacture	Installation/ Construction	Recycle/ Disposal	Row Score
Diversity	1	2	2	2	7
Work Unions	3	3	4	4	14
Safety	1	2	4	3	10
Child Labor	3	4	4	4	14
Community Involvement	2	2	2	3	9
Accessibility	1	4	4	4	13
Time	0	2	4	2	8
Wages	2	3	4	4	13
Column Score	12	22	28	26	89/128 69.5%

Working Conditions Matrix (Pile)

	Material Excavation	Product Manufacture	Installation/ Construction	Recycle/ Disposal	Row Score
Diversity	1	2	2	2	7
Work Unions	3	3	4	4	14
Safety	1	3	2	3	9
Child Labor	3	4	4	4	14
Community Involvement	2	2	2	3	9
Accessibility	1	3	4	3	11
Time	0	2	4	2	8
Wages	2	3	4	3	12
Column Score	12	22	26	24	85/128 66.4%

Figure 7. Working condition matrix for two-alternate deep foundation systems

© ASCE 2014

Table 2. Design Satisfaction for Piles & Caisson

	Caisson	Piles
Functionality	4	4
Maintenance	4	4
Space Occupied	4	2
Architectural Aesthetic	4	2
Service Life	4	4
Column Score	20/20	16/20
	100 %	80 %

Economic Sustainability

The economic aspects of the two evaluated alternatives included the purchase, transportation, and construction costs. The rates of these were found at several online suppliers and construction databases. The driving of the piles; and the drilling of the caisson, were given at a rate per vertical linear foot (VLF). For the splicing of the piles; and excavating the bell shape at the bottom of the caisson, the rate was listed for each unit. The piles were driven at a depth of 55 feet. Since the PP 20" x .375" came at a maximum length of 50 feet, splicing was required for all 14 piles. The total construction cost was calculated to be $43,461 at $50.0/VLF. To purchase the units, the rate of $595/metric-ton was multiplied by the weight of steel. The volume and weight were related by the density of steel. The price of 14 piles was $16,410. The caisson was also driven at a depth of 55 feet and required reinforcement and special excavation of the bottom bell. The price to drill the bell shaped shaft and fill it with concrete was calculated to be $10,221 at $158.62/VLF. The price to purchase the concrete and rebar was $4,208.

After estimating the purchase and construction costs, it is noticeable that the piles costs stand out with four times those of the caisson; this is due to the fact that there are 14 individual piles with a splice for each. The caisson was much cheaper because it is a single unit. In addition, the transportation costs were assumed to be part of the purchase cost since it was nearly impossible to get an accurate estimate; and to avoid any possible discrepancies in the side-by-side comparison of these alternatives.

CONCLUSION

In this study, two commonly used deep foundation systems were assessed based on the three pillars of sustainability: environmental, economic and social aspects. Piles and Caisson were selected for sustainability evaluation based on site-specific data pertaining to General Chicago area over their entire design life period.

SimaPro was used to perform life-cycle assessment of two alternate deep foundations and based on the results, it was concluded that caisson system would be more environmentally sustainable than piles. The piles were the leading contributor to the negative impact on every category for the Eco Indicator 99 method causing 60% more damage to the environment. The amount of steel in the piles required high

© ASCE 2014

energies to extract, mil, and form. Furthermore, the 14 piles required high energy to construct compared to the single drilling and placing for the caisson.

Similarly, both economic evaluation and social impact assessment proved caisson foundation to be more sustainable, since, costs associated with the purchase, transportation and driving of caisson are around 4.2 times cheaper than that of piles. This was because the number of pipe piles required to achieve the desired capacity was far too many and that drove the high costs. However, social sustainability can be subjective and vary from one project site to another.

Overall, this study shows the approach that can be followed for the design of sustainable foundation systems, or in general built infrastructure systems, in civil engineering practice.

REFERENCES

Coduto, D. P. (2001). *Foundation design principles and practices* 2nd Ed., Prentice-Hall, New Jersey.

B2-Consultants LLC. (2014). "Free Construction Cost Data." http://www.allcostdata.info/detail.html/023664700/Pile,-steel,-pipe,-splices,-not-in-leads-18%22-dia (March 4, 2014).

B2-Consultants LLC. (2014). "Free Construction Cost Data." http://www.allcostdata.info/detail.html/023664100/Pile,-steel,-pipe,-50'-L-18%22-dia,-59-lb/LF,-no-conc (March 4, 2014).

© ASCE 2014

GREEN BUILDING RATING SYSTEMS AND ENVIRONMENTAL IMPACTS OF ENERGY CONSUMPTION FROM AN INTERNATIONAL PERSPECTIVE

Sami G. Al-Ghamdi[1] and Melissa M. Bilec[2]

[1] Department of Civil and Environmental Engineering, University of Pittsburgh, 949 Benedum Hall, 3700 O'Hara Street, Pittsburgh, PA 15261-2294; PH (412) 624-9870; FAX (412) 624-0135; email: sga8@pitt.edu

[2] Department of Civil and Environmental Engineering, University of Pittsburgh, 153 Benedum Hall, 3700 O'Hara Street, Pittsburgh, PA 15261-2294; PH (412) 648-8075; FAX (412) 624-0135; email: mbilec@pitt.edu

ABSTRACT

The aim of this research was to explore potential benefits and challenges of adopting green building rating system on a global level. A Building Information Modeling (BIM) of an illustrative building was developed and situated in different international locations with the goal of representing varying climate types, economic conditions and energy sources. The base BIM was individually changed to meet local codes, reasonable heating and cooling systems while in compliance with the Leadership in Energy and Environmental Design (LEED). Life cycle environmental impacts related to energy use with electricity generation mix were calculated. Discrepancies were observed in the results between the different sites; with differences clearly increase with more diversified energy sources. Range of variation in equivalent CO_2 emissions was over 10,000 ton for the same building and the same level of LEED certification. We explored the need for LEED to require buildings with higher environmental impacts to achieve higher levels of energy performance based on associated impacts.

Keywords: LEED Rating Systems; Life Cycle Assessment (LCA); Building Information Modeling (BIM); Commercial Buildings; Operational Environmental Impact in Buildings

INTRODUCTION

In the United States, buildings are responsible for 41% of energy consumption and 40% of CO_2 emissions with the projection of those numbers to grow fast in the next 25 years (US EIA 2012). Internationally, buildings accounts for about one third of the energy use (IEA and OECD 2010). Reducing energy use and its environmental impact by promotion of energy efficiency is one of the main goals of green building rating systems. Leadership in Energy and Environmental Design (LEED) is one of the prominent international green building rating systems. LEED was developed by the U.S. Green Building Council (USGBC) and has evolved through several versions,

© ASCE 2014

starting with the pilot version in 1998 to the fourth version in November 2013. LEED is currently the dominant green building rating system in the United States market and is being adapted to many markets worldwide (Fowler and Rauch 2006). Although LEED was initiated in the US, it is now establishing its presence globally providing internationally adopted design, construction and operational guidelines and standards (Thilakaratne and Lew 2011). The current version of LEED is to a large extent based on energy models, though verification of performance is permeating the certification documentation. LEED Energy and Atmosphere (EA) credits can be obtained by illustrating reductions in anticipated energy reduction via baseline models and design models. Two buildings in two different locations may be awarded LEED EA credits by reducing energy consumption by 10% compared to their baselines while in fact, they have a large differences in the environmental impact reduction because electricity generation issues have been found to be the largest variable (Adalberth et al. 2001).

Life cycle and systems thinking are essential in solving pressing environmental concerns. As such, a discussion on Life Cycle Assessment (LCA) integration appeared in many panel discussions and working groups of the U.S. Green Building Council (USGBC) beginning in 2006, leading to 2009 version (Trusty 2006). The 2009 version introduced a fundamental change in how LEED credits were 'weighted.' This weighting was adapted using life cycle assessment considerations that give the largest share of points to the energy section for its significant environmental and human health impacts. In the new weighting scheme, building impacts are described with respect to 13 impact categories e.g. greenhouse gas emissions, fossil fuel depletion, water use, etc. The categories were according to TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) that was developed specifically for the United States by EPA (US Environmental Protection Agency). After that it compares the impact categories to each other according to BEES (Building for Environmental and Economic Sustainability), a tool was developed by the NIST (US National Institute of Standards and Technology) (Bare 2002; Gloria et al. 2007; USGBC 2008). This research continues the life-cycle thinking with the intention to quantitatively investigate international variations in buildings energy environmental performance in relation to the LEED rating system. Applying LCA to building rating systems at a systems level, especially rating systems targeting international markets, is critical in understanding and developing thoughtful and meaningful environmental reductions.

METHODOLOGY

The aim of this research was to explore potential benefits and challenges of adopting green building rating system like LEED on a global level. The authors investigated operational environmental impacts of a large representative office building in different parts of the world. A Building Information Modeling (BIM) of the building was developed and situated in 400 locations with the goal of representing varying

© ASCE 2014

climate types, economic conditions and energy sources. The base BIM was individually changed to meet local codes, reasonable heating and cooling systems while in compliance with the Leadership in Energy and Environmental Design (LEED). This framework paper will cover in details the following explanatory locations among the 400 included the original study: Nathrop, Colorado, United States; Cabo de Santo Agostinho, Pernambuco, Brazil; Guangzhou, Guangdong, China; and Villeurbanne, Rhône-Alpes, France.

The case study building consists of 20 floors above ground and two underground, with total area of 606,875 ft^2 (56,381 m^2). The building type was designed as an office that was used for general office space, professional office, or administrative offices. Operational schedules were set to be the same according to the local time and calendar of each location taking into account holidays and daylight saving time. All building materials that shape the thermal characteristics and other variables in each location (independently from the other sites) comply with the suitable codes as it will be clarified subsequently. As shown in Table 2, all construction materials meet the minimum R-value requirements ASHRAE 90.1 2007 for each location. We used BIM compatible energy analysis tools that meets the LEED requirement for calculating a building's baseline performance according to ANSI/ASHRAE/IESNA Standard 90.1-2007, Appendix G (ASHRAE et al. 2007). The HVAC system was Central Variable Air Volume (VAV), HW Heat, Chiller 5.96 COP, Boilers 84.5 eff. Other characteristics and variables have been identified in accordance with the following summary:

- HVAC efficiency and lighting power density were set to meet the ASHRAE 90.1 2007 (ASHRAE et al. 2007).
- Equipment power density was set to meet the California 2005 Title 24 Energy Code (California Building Standards Commission 2005).
- Occupancy density and ventilation were set to meet ASHRAE 62.1 2007 (ASHRAE et al. 2007).
- The HVAC type default and any other characteristics were set following the 2003 CBECS (Commercial Buildings Energy Consumption Survey) (US EIA 2003).
- Source of energy considered to be natural gas for the building space heating and water heating, while using electricity for the rest of the energy needs.

Life Cycle Assessment (LCA) was then used to analyze the environmental impacts due to the building's energy consumption in the four locations focusing on life cycle energy use and greenhouse gas emissions. The four steps standard LCA methodology was used following the International Organization for Standardization (ISO) in ISO 14040 and 14044 (ISO 1997; ISO 2006). The first step, Goal and Scope, considered the entire life cycle of the energy used in the building. The functional unit was identified to be the building (annual energy consumption of electricity and fuel on site). The second step, Life Cycle Inventory (LCI), inventory data were drawn in the

© ASCE 2014

following order from: US Life Cycle Inventory-based databases (USLCI) (NREL 2010); Ecoinvent (Frischknecht et al. 2005); then other databases if unit process were not available (ESU Services Ltd. 1996; Franklin Associates Ltd. 1998). For the electric power plant source and as shown in Table 1, data was collected for the US site from the US plants from US Environmental Protection Agency, EGRID 2006 Data and 2004 Plant Level Data (US EPA 2012); the other three sites was obtained from 2009 Carbon Monitoring for Action (CARMA) database (CARMA 2009) and International Energy Agency (IEA) database (IEA 2009). The third step, Life Cycle Impact Assessment (LCIA), the inputs and outputs of each process were calculated using the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) 2 V3.01. The fourth step, interpretation where the results and conclusion are shown in the following section.

Table 1. Power plant energy sources in the different four locations.

Energy Sources	Nat'l – 039 Nathrop, CO, USA	Int'l – 035 Cabo, PE, Brazil	Int'l – 074 Guangzhou, China	Int'l – 111 Villeurbanne, France
Coal	67.80%	2.22%	88.00%	2.09%
Oil	0.00%	2.34%	0.89%	0.42%
Gas	22.60%	2.90%	0.00%	1.67%
Nuclear	0.00%	3.00%	0.00%	77.93%
Hydro	4.30%	84.54%	10.98%	17.75%
Renewable	5.20%	5.00%	0.13%	0.14%
Other	0.10%	0.00%	0.00%	0.00%

© ASCE 2014

Table 2. Detailed description of the thermal properties and construction materials in the four case study buildings.

Building Components Category	ASHRAE Climate Zone 6B (Cold, Dry) **Nathrop, CO, United States** Location ID: Nat'l - 039		ASHRAE Climate Zone 1A (Very Hot, Humid) **Cabo de Santo Agostinho, PE, Brazil** Location ID: Int'l - 035		ASHRAE Climate Zone 5A (Cool, Humid) **Guangzhou, Guangdong, China** Location ID: Int'l - 074		ASHRAE Climate Zone 4A (Mixed, Humid) **Villeurbanne, RA, France** Location ID: Int'l - 111		Total Modelled Area
	Thermal properties	**Construction Layers**	**Thermal properties**	**Construction Layers**	**Thermal properties**	**Construction Layers**	**Thermal properties**	**Construction Layers**	
Roofs	R20 over Roof Deck U-Value: 0.04	1. Blt-Up Roof 3/8in 2. Bldg Paper Felt 3. MinBd 3in R-10.4 4. MinBd 3in R-10.4 5. Wood Sft 3/4in	R15 over Roof Deck U-Value: 0.06	1. Blt-Up Roof 3/8in 2. Bldg Paper Felt 3. MinBd 2in R-7 4. MinBd 2in R-7 5. Wood Sft 3/4in	R20 over Roof Deck U-Value: 0.04	1. Blt-Up Roof 3/8in 2. Bldg Paper Felt 3. MinBd 3in R-10.4 4. MinBd 3in R-10.4 5. Wood Sft 3/4in	R20 over Roof Deck U-Value: 0.04	1. Blt-Up Roof 3/8in 2. Bldg Paper Felt 3. MinBd 3in R-10.4 4. MinBd 3in R-10.4 5. Wood Sft 3/4in	38,963 ft^2 (3,620 m^2)
Exterior Walls	R13+7.5 Metal Frame U-Value: 0.07	1. Face Brick 4in 2. Bldg Paper Felt 3. Polyurethane 1.25in 4. MinWool Batt R13 w/Mtl Frame 16in oc 5. GypBd 5/8in	R13 Metal Frame U-Value: 0.16	1. Face Brick 4in 2. Bldg Paper Felt 3. MinWool Batt R13 w/Mtl Frame 16in oc 4. GypBd 5/8in	R13 Metal Frame Wall U-Value: 0.16	1. Face Brick 4in 2. Bldg Paper Felt 3. MinWool Batt R13 w/Mtl Frame 16in oc 4. GypBd 5/8in	R13+7.5 Metal Frame U-Value: 0.07	1. Face Brick 4in 2. Bldg Paper Felt 3. Polyurethane 1.25in 4. MinWool Batt R13 w/Mtl Frame 16in oc 5. GypBd 5/8in	166,337 ft^2 (15,453 m^2)
	R13 Wood Frame Wall U-Value: 0.08	1. Wood Shingle 2. Bldg Paper Felt 3. Wood Sft 3/4in 4. MinWool Batt R13 w/(2x4) Frame 16in oc 5. GypBd 5/8in	R13 Wood Frame Wall U-Value: 0.08	1. Wood Shingle 2. Bldg Paper Felt 3. Wood Sft 3/4in 4. MinWool Batt R13 w/(2x4) Frame 16in oc 5. GypBd 5/8in	R13 Wood Frame Wall U-Value: 0.08	1. Wood Shingle 2. Bldg Paper Felt 3. Wood Sft 3/4in 4. MinWool Batt R13 w/(2x4) Frame 16in oc 5. GypBd 5/8in	R13 Wood Frame Wall U-Value: 0.08	1. Wood Shingle 2. Bldg Paper Felt 3. Wood Sft 3/4in 4. MinWool Batt R13 w/(2x4) Frame 16in oc 5. GypBd 5/8in	5,312 ft^2 (494 m^2)
Interior Walls	R0 Metal Frame Wall U-Value: 0.41	1. GypBd 5/8in 2. Air Space 3. GypBd 5/8in	R0 Metal Frame Wall U-Value: 0.41	1. GypBd 5/8in 2. Air Space 3. GypBd 5/8in	R0 Metal Frame Wall U-Value: 0.41	1. GypBd 5/8in 2. Air Space 3. GypBd 5/8in	R0 Metal Frame Wall U-Value: 0.41	1. GypBd 5/8in 2. Air Space 3. GypBd 5/8in	228,900 ft^2 (21,265 m^2)
Interior Floors	Interior 4in Slab Floor U-Value: 0.74	1. Conc HW 140lb 4in	Interior 4in Slab Floor U-Value: 0.74	1. Conc HW 140lb 4in	Interior 4in Slab Floor U-Value: 0.74	1. Conc HW 140lb 4in	Interior 4in Slab Floor U-Value: 0.74	1. Conc HW 140lb 4in	567,905 ft^2 (52,760 m^2)
Raised Floors	R12.5 Mass Floor U-Value: 0.06	1. Polystyrene 3in 2. Conc HW 140lb 4in 3. Carpet & Fiber Pad	U 0.322 Mass Floor U-Value: 0.24	1. Conc HW 140lb 10in 2. Carpet & Fiber Pa	R6.3 Mass Floor U-Value: 0.10	1. Polystyrene 1in 2. Conc HW 140lb 4in 3. Carpet & Fiber Pad	R8.3 Mass Floor U-Value: 0.09	1. Polystyrene 2in 2. Conc HW 140lb 4in 3. Carpet & Fiber Pad	720 ft^2 (67 m^2)
Slabs On Grade	Concrete slab R15 perim U-Value: 0.01	1. R15 perimeter slab insulation 2. Soil 8in 3. Conc HW 140lb 8in 4. Carpet & Fiber Pad	Uninsulated concrete slab U-Value: 0.03	1. Soil contact for uninsulated slab 2. Soil 8in 3. Conc HW 140lb 8in 4. Carpet & Fiber Pad	Uninsulated concrete slab U-Value: 0.03	1. Soil contact for uninsulated slab 2. Soil 8in 3. Conc HW 140lb 8in 4. Carpet & Fiber Pad	Uninsulated concrete slab U-Value: 0.03	1. Soil contact for uninsulated slab 2. Soil 8in 3. Conc HW 140lb 8in 4. Carpet & Fiber Pad	938 ft^2 (87 m^2)
Under-Ground Walls	R7.5 8in CMU UnderGnd U-Value: 0.02	1. R7.5 perimeter slab insulation 2. Soil 8in 3. Conc HW 140lb 8in	R0 8in CMU UnderGnd U-Value: 0.03	1. Soil contact for uninsulated slab 2. Soil 8in 3. Conc HW 140lb 8in	R0 8in CMU UnderGnd assembly U-0.645 U-Value: 0.03	1. Soil contact for uninsulated slab 2. Soil 8in 3. Conc HW 140lb 8in	R0 8in CMU UnderGnd assembly U-0.645 U-Value: 0.03	1. Soil contact for uninsulated slab 2. Soil 8in 3. Conc HW 140lb 8in	17,901 ft^2 (1,663 m^2)
Under-Ground Slabs	Concrete slab R15 perim U-Value: 0.01	1. R15 perimeter slab insulation 2. Soil 8in 3. Conc HW 140lb 8in 4. Carpet & Fiber Pad	Uninsulated concrete slab U-Value: 0.03	1. Soil contact for uninsulated slab 2. Soil 8in 3. Conc HW 140lb 8in 4. Carpet & Fiber Pad	Uninsulated concrete slab U-Value: 0.03	1. Soil contact for uninsulated slab 2. Soil 8in 3. Conc HW 140lb 8in 4. Carpet & Fiber Pad	Uninsulated concrete slab U-Value: 0.03	1. Soil contact for uninsulated slab 2. Soil 8in 3. Conc HW 140lb 8in 4. Carpet & Fiber Pad	37,305 ft^2 (3,466 m^2)
Fixed Windows	North Facing Windows: Double Low-E Clear U-SI 1.68, U-IP 0.30, SHGC 0.44, VLT 0.70 (96 windows). U-Value: 1.68 W / (m^2-K), SHGC: 0.44 , Vlt: 0.70		South Facing Windows: Single Clear-L Tint (78 windows). U-Value: 4.99 W / (m^2-K), SHGC: 0.25 , Vlt: 0.13		North Facing Windows: Double Refl Tint U-SI 2.98, U-IP 0.53, SHGC 0.25, VLT 0.16 (96 windows). U-Value: 2.98 W / (m^2-K), SHGC: 0.25 , Vlt: 0.16		North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (96 windows). U-Value: 1.74 W / (m^2-K), SHGC: 0.40 , Vlt: 0.60		19,114 ft^2 (1,776 m^2)
	Non-North Facing Windows: Double Low-E Clear U-SI 1.68, U-IP 0.30, SHGC 0.44, VLT 0.70 (380 windows). U-Value: 1.68 W / (m^2-K), SHGC: 0.44 , Vlt: 0.70		Non-South Facing Windows: Single Clear-L Tint (398 windows). U-Value: 4.99 W / (m^2-K), SHGC: 0.25 , Vlt: 0.13		Non-North Facing Windows: Double Refl Tint U-SI 2.98, U-IP 0.53, SHGC 0.25, VLT 0.16 (380 windows). U-Value: 2.98 W / (m^2-K), SHGC: 0.25 , Vlt: 0.16		Non-North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (380 windows). U-Value: 1.74 W / (m^2-K), SHGC: 0.40 , Vlt: 0.60		49,483 ft^2 (4,597 m^2)

© ASCE 2014

FINDINGS

The energy modeling results are presented in Table 3, the four sites varied from 550 to 591 MJ/m^2/year in energy use intensity (EUI) and with Energy Total Cost ranging from ~$869,000 to ~$1,214,000. Differences are clearly visible due to climatic variations, where there is a large variation in the consumption of natural gas for heating (see Figure 1 and Figure 2). These disparities exist and will continue to exist for climate differences. Nevertheless, LEED provides clear benefits where the economical savings will be between 10% as a prerequisite of minimum energy performance to 50% as the maximum credit of improvement in energy performance.

Table 3. Energy consumption and costs at the different four locations.

Variable/Location	Nat'l – 039 Nathrop, CO, USA	Int'l – 035 Cabo, PE, Brazil	Int'l – 074 Guangzhou, China	Int'l – 111 Villeurbanne, France
EUI (MJ/m²/year)	591	655	626	550
Electric (kWh)	8,113,823	10,041,920	9,487,614	7,893,265
Electric Rate ($/kWh)	$0.090	$0.120	$0.094	$0.107
Electric Cost ($)	728,621	1,205,030	890,887	842,211
Fuel (MJ)	4,095,868	799,637	1,133,002	2,587,431
Fuel Rate ($/MJ)	$0.007	$0.012	$0.007	$0.010
Fuel Cost ($)	$29,012	$9,444	$8,416	$27,123
Energy Total Cost ($)	$757,633	$1,214,474	$899,303	$869,334

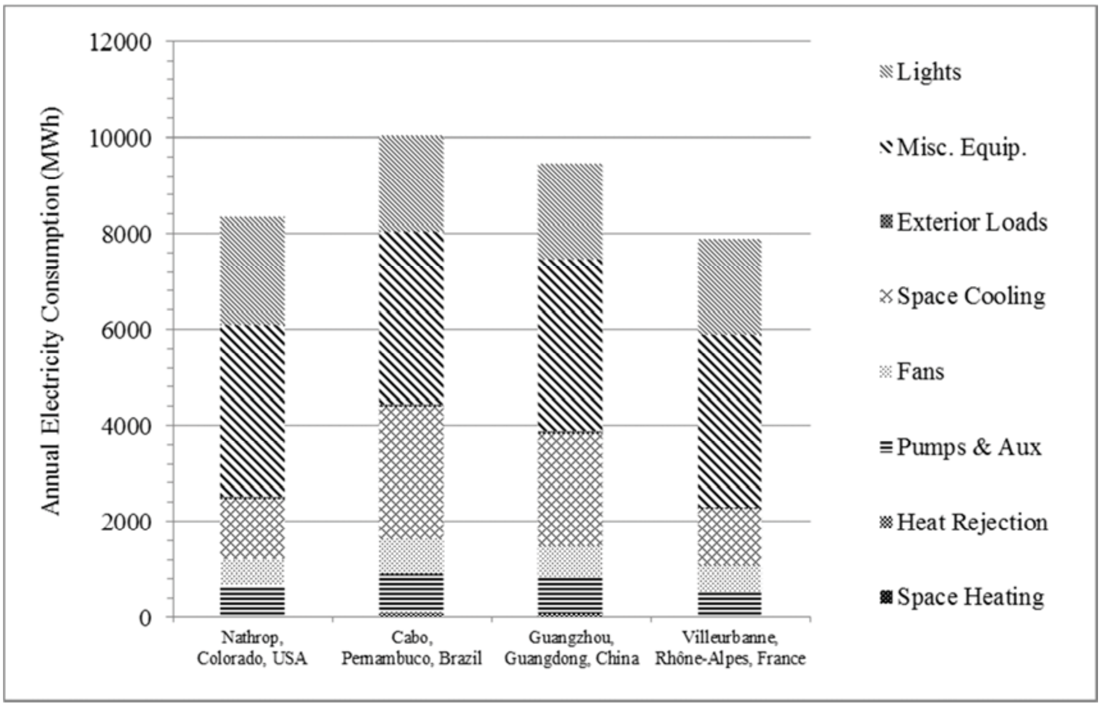


Figure 1. Annual electricity consumption broken down by building systems.

© ASCE 2014

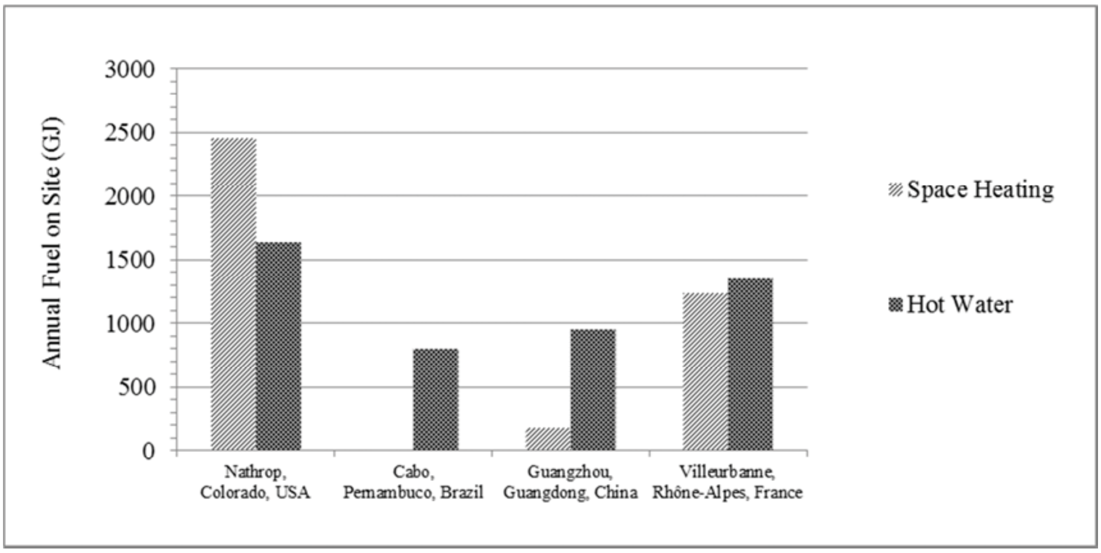


Figure 2. Annual fuel on site consumption broken down by type of use.

However, the environmental results appear to be more complicated when analyzing environmental loads for buildings around the world, which rely on different energy sources. Essential discrepancies were observed in the results between sites; with differences clearly increasing with more diversified energy sources. Range of variation was from 746,880 kg CO_2eq in France with dominant energy source of nuclear to 9,967,233 kg CO_2eq in China with the dominant energy source of coal.

Table 4 illustrates the extent of the discrepancy between the results of the four buildings. Variations are not equal among all environmental categories, where we can notice greater differences between buildings within the same environmental category or compered to other categories as shown in Figure 3. In the global warming category the equivalent CO_2 emissions from the building in France represent only 9% of the emissions from the building in the United States and 7% from the building in the China. Moreover, the same emissions from the building in Brazil represent only 20% compared to those in the United States and 17% for China. Nevertheless, we can see disparity in the environmental performance of the same building in different categories. For instance, while the building in Brazil is responsible for only 10% of the global warming potential, it dominates the ozone depletion category by 68% and by 36% in the non-carcinogenics category compared to other buildings.

Through these findings, our recommendation is that future versions of LEED – especially as LEED expands internationally – consider modification towards GHG reduction targets in addition to energy reductions. Another option is that future LEED versions may want to consider that buildings with higher environmental impacts due to energy sources should be required to achieve higher levels of energy saving, efficiency and/or on-site generation based on the associated impacts instead of fixed percentage of energy savings.

© ASCE 2014

Table 4. Environmental impacts due to energy usage at the different four locations.

Environmental Category	Nat'l – 039 Nathrop, CO, USA	Int'l – 035 Cabo, PE, Brazil	Int'l – 074 Guangzhou, China	Int'l – 111 Villeurbanne, France
Global Warming (kg CO2 eq)	7,991,402	2,001,841	9,967,233	746,880
Acidification (H+ moles eq)	4,509,202	720,255	5,728,422	439,814
Carcinogenics (kg benzene eq)	6,813	3,616	10,010	924
Non Carcinogenics (kg toluene eq)	29,462,467	43,930,190	36,311,050	11,859,492
Respiratory Effects (kg PM2.5 eq)	12,251	3,523	14,826	1,283
Eutrophication (kg N eq)	978	358	1,307	123
Ozone Depletion (kg CFC-11 eq)	0.006	0.042	0.007	0.006
Ecotoxicity (kg 2,4-D eq)	5,789,761	6,318,070	9,004,123	1,363,379
Smog (kg NOx eq)	35,159	22,735	25,928	2,300

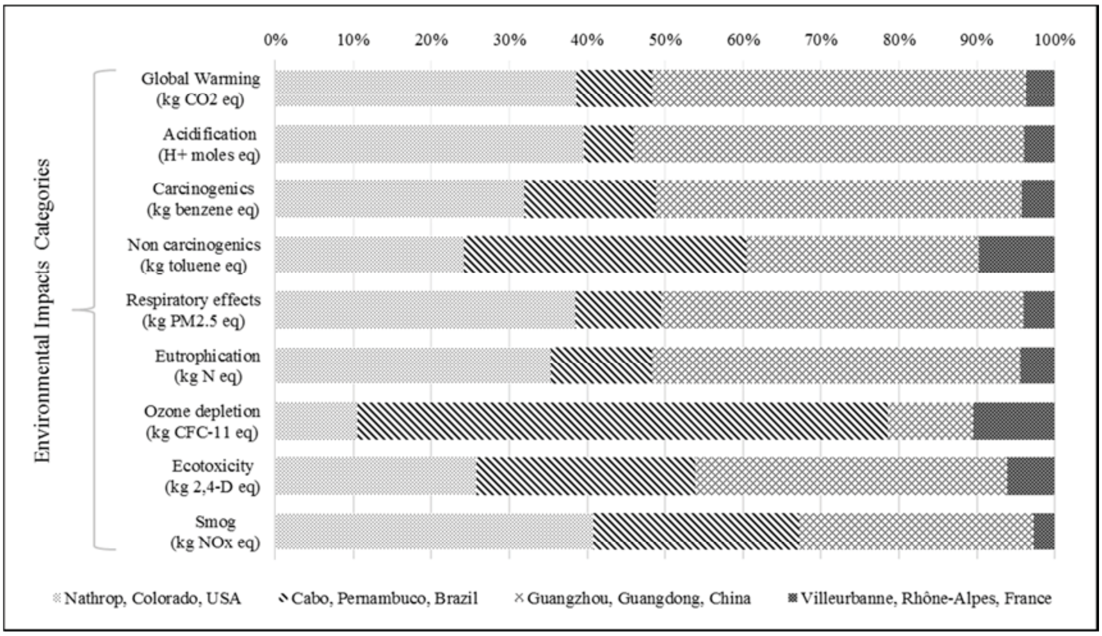


Figure 3. Contribution ratios of each building in the environmental impacts due to energy usage at the different locations.

CONCLUSION

Given the research conducted herein and in the context of green building rating systems, we confirmed that energy sources and associated environmental impacts matter significantly. Since LEED is currently undergoing international expansion, consideration of energy sources for buildings should be reflected in future LEED revisions, with a particular suggestion of targeted goals versus aggregated certifications. The results revealed that location specific results, when paired with life cycle assessment, can be an effective means to achieve a better understanding and reduction of the adverse environmental impacts resulting from energy consumption.

© ASCE 2014

The significance of our findings relies on the fact that LEED system has rapidly expanded into a global system to cover most of the world. In 2013, about 4,900 cities were registered with green building profiles on the USGBC's Green Building Information Gateway (GBIG 2013). Today there are more than 10 billion square feet of building space certified by LEED. Also, 1.5 million square feet get certified each day in 135 countries (USGBC 2013). With tremendous benefits on many of the challenges that we face today, where for example, seventy to ninety percent of the environmental impact categories occur in the use phase. Finally for future research, we are working to expand this research to include results of the larger sample of building and other issues such as renewable energy for a better understanding of the energy life cycle thinking in green building rating systems.

ACKNOWLEGMENT

This research was supported by a scholarship from the Ministry of Higher Education in the Kingdom of Saudi Arabia, through the Saudi Arabian Cultural Mission to the US (SACM) Washington, DC (64581). We would like to acknowledge the University of Pittsburgh's Mascaro Center for Sustainable Innovation for their support. This material is based upon work supported by the National Science Foundation under EFRI-SEED (1038139). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

Adalberth, K., Almgren, A., and Petersen, E. (2001). "Life-cycle assessment of four multi-family buildings." *International Journal of Low Energy and Sustainable Buildings*, 2, 1-21.

ASHRAE, ANSI, and IESNA (2007). *Standard 62.1-2007: Ventilation for Acceptable Indoor Air Quality*, ASHRAE (American Society of Heating and Refrigerating and Air-Conditioning Engineers), ANSI (American National Standards Institute) and IESNA (Illuminating Engineering Society of North America), Atlanta, GA.

ASHRAE, ANSI, and IESNA (2007). *Standard 90.1-2007: Energy Standard For Buildings Except Low-Rise Residential Buildings*, ASHRAE (American Society of Heating and Refrigerating and Air-Conditioning Engineers), ANSI (American National Standards Institute) and IESNA (Illuminating Engineering Society of North America), Atlanta, GA.

Bare, J. C. N. G. A. P. D. W. M. T. (2002). "TRACI - The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts." *Journal of Industrial Ecology*, 6(3/4), 49-78.

© ASCE 2014

California Building Standards Commission (2005). *2005 California Energy Code: California Code of Regulations, Title 24, Part 6*, California Building Standards Commission, Sacramento, CA.
CARMA (2009). "Power Plant Data." *Carbon Monitoring for Action (CARMA) V 3.0 - with year 2009 data* Center For Global Development, Washington, DC.
ESU Services Ltd. (1996). "ETH-ESU LCI 96." *ESU Services Ltd.*
Fowler, K. M., and Rauch, E. M. (2006). "Sustainable Building Rating Systems." Pacific Northwest National Laboratory.
Franklin Associates Ltd. (1998). "Franklin LCI US 98." *Franklin Associates Ltd*
Frischknecht, R., Jungbluth, N., Althaus, H.-J., Doka, G., Dones, R., Heck, T., Hellweg, S., Hischier, R., Nemecek, T., Rebitzer, G., and Spielmann, M. (2005). "The ecoinvent Database: Overview and Methodological Framework." *The international journal of life cycle assessment.*, 10(1), 3.
GBIG (2013). "Places: Explore green building activity by location.", <http://www.gbig.org/>. (1/23/2014).
Gloria, T. P., Lippiatt, B. C., and Cooper, J. (2007). "Life Cycle Impact Assessment Weights to Support Environmentally Preferable Purchasing in the United States." *Environmental Science & Technology*, 41(21), 7551-7557.
IEA (2009). "Electricity Generation by Fuel." *IEA Statistics - with year 2009 data*, International Energy Agency (IEA), Paris, France.
IEA, and OECD (2010). "Energy balances of OECD countries." International Energy Agency, Organisation for Economic Co-operation Development, Paris.
ISO (1997). *Environmental management - Life cycle assessment: Principles and framework*, International Organization for Standardization (ISO), Switzerland, Geneva.
ISO (2006). *Environmental management - life cycle assessment: requirements and guidelines*, International Organization for Standardization (ISO), Switzerland, Geneva.
NREL (2010). "US Life-Cycle Inventory Database (USLCI)." National Renewable Energy Laboratory (NREL),, Golden, CO.
Thilakaratne, R., and Lew, V. (2011). "Is LEED Leading Asia?: an Analysis of Global Adaptation and Trends." *Procedia Engineering*, 21(0), 1136-1144.
Trusty, W. (2006). "Integrating LCA into LEED Working Group A (Goal and Scope). Interim Report #1." Athena Institute and USGBC.
US EIA (2003). "Commercial buildings energy consumption survey (CBECS)." US Energy Information Administration (EIA), Office of Integrated Analysis and Forecasting, U.S. Dept. of Energy, Washington, DC.
US EIA (2012). "Annual Energy Outlook." US Energy Information Administration (EIA), Office of Integrated Analysis and Forecasting, U.S. Dept. of Energy, Washington, DC.
US EPA (2012). "Plant Level Data." *eGRID 2012 V 1.0 - with year 2009 data* US Environmental Protection Agency Washington, DC.
USGBC (2008). "LEED 2009 Weightings Background."Washington, DC.
USGBC (2013). "About USGBC." <http://www.usgbc.org/about>. (2/7/2014).

© ASCE 2014

Urban agriculture characterized by life cycle assessment and land use change

Stephen Fisher, Ph.D., P.E.[1], and Arunprakash Karunanithi, Ph.D.[2]

[1]Tetra Tech, 216 16th St., Ste 1500, Denver, CO 80202-5129; PH. (303) 312-8849; FAX (303) 295-2818; email: stephen.fisher@tetratech.com
[2]Department of Civil Engineering, University of Colorado Denver, 1200 Larimer Street, NC 3027, Campus Box 113, P.O. Box 173364, Denver, CO 80217; PH (303) 556-2370; email: arunprakash.karunanithi@ucdenver.edu

ABSTRACT

The world's urban population surpassed the non-urban population for the first time in 2009. This marks what has been a steady global shift of providing more food to places it is not grown. Because food accounts for over 10 percent of the carbon footprint for the typical American city, this study adopts a social-ecological-infrastructural systems framework, a large component of which is recognizing urban activities and sectors belonging to infrastructure inside *and* outside the urban boundary. This is a key way to examine the embodied, life-cycle properties of the food we eat in cities. Preliminary results of scenarios of land use change and vegetable production for both distant farmland and urban settings found that shifts resulting from urban vegetable production are favorable in terms of greenhouse gas emissions, water use, and soil organic carbon. The results to-date indicate that state and local policy could remove hurdles to urban agricultural production with these data supporting claims that benefits outweigh costs.

Urban Agriculture in the Context of Urban Sustainability

In 2009, the world's urban population surpassed the non-urban population for the first time (World Resources Institute [WRI] 2010). This marks what has been a steady global shift of providing more food to places it is not grown. In the U.S., for example, depending on the vegetable variety and time of year, conventional produce travels, on average, from 500 to over 2,000 miles to terminal markets in the U.S. (Weber and Matthews 2008). The vast majority of American farmland is devoted to the main commodity crops (i.e., corn, cotton, rice, soy, and wheat) that require vast fields, large operations, and economies of scale. However, little of the food we eat comes directly from these crops – most is used as animal feed or exported. Demand for fresh vegetables is met from a surprisingly small amount of farmland. But constraints on traditional farmland are growing. These include water scarcity, development pressure, degrading soils, nutrient runoff, and cost of inputs. Urban vegetable production is a viable land use change to meet these challenges.

There is enough arable land area in the typical American city to support meeting all its fresh vegetable demand many times over. In one study for Denver, Colorado, it was found that there is over 10 times the land available to meet city demand for broccoli, carrot, spinach, tomato, bell pepper, and potato (Brett, et al.

© ASCE 2014

2013). Also, in contrast to commercial farming, urban vegetable production as food, health, and security, is advancing popularly on its own as an advocacy platform, hobby, business, and occupation (Kloppenburg 2000). Some urban areas around the globe provide up to 90 percent of fresh vegetable consumption through urban gardens, others almost none (Cuba 2008).

But the link between the food we eat and urban sustainability exists equally whether the food comes from a farm far away or one's own back yard. What commercial growers provide to supermarkets is a significant cog in the food system and they rely on large contributions of distributed infrastructure from farm to table. In fact, as shown on Figure 1, the food urbanites eat ranks significantly with other notable urban sectors, such as transportation, housing, and energy, in terms of fossil fuel consumption, emissions, water use, waste, and economic activity (Hillman and Ramaswami 2010, Decker 2000).

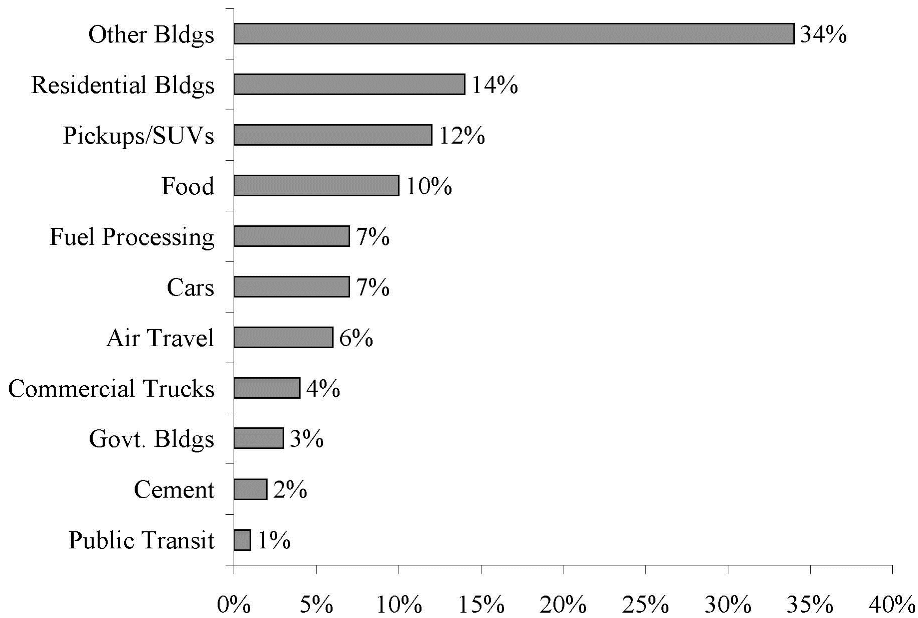


Figure 1. Greenhouse gas emissions summary for Denver in 2005 (from Ramaswami, et al. 2008).

Other notable characteristics of urban food are that it comprises 17 percent of fossil fuels use, 12.7 percent of the post-consumer waste stream, and 13 percent of consumer spending (Heller and Keoleian 2000, IPCC 2008, Ramaswami, et al. 2008). Even with the small fraction of all farmland devoted to vegetable production, fruit and vegetables contribute about 8 percent of greenhouse gas emissions from all food, 4 percent of water embedded in food products, and 15 percent of embodied energy (Institute of Grocery Distribution [IGD] 2007).

This paper adopts a social-ecological-infrastructural systems (SEIS) framework, a large component of which is recognizing urban activities and sectors belonging to infrastructure inside *and* outside the urban boundary (Ramaswami, et al.

© ASCE 2014

2012). The framework establishes the importance of including WRI Greenhouse Gas Protocol Scope 3 emissions and other indirect, upstream supply-chain footprints when they are a large component of total emissions and footprints of urban activities. This is a key way to examine the embodied, life-cycle properties of the food we eat in cities.

In counting the impacts of the production, processing, and transport of food, one must extend the boundary however far it exists. "...to address environmental sustainability both in terms of resource use and global pollution impacts, activities and infrastructures within city boundaries must be explicitly integrated with transboundary infrastructures that span hundreds of miles and draw in vast quantities of natural resources, directly or indirectly, to meet city demand..." (Ramaswami, et al. 2012). This is a main focus of greenhouse gas (GHG) accounting and reporting for material flows in and out of the [usually jurisdictional] urban boundary. For example, some infrastructure services utilize more fossil fuel outside city boundaries than within (Ramaswami, et al., 2012).

Life Cycle of Vegetable Production

The life cycle assessment (LCA) is a framework for identifying impacts of a product's manufacture, use, reuse, or disposal. The LCA is typically conducted on manufactured products, but the concept has also been applied to operations research, supply chain analysis, human resources, and a wide variety of capital projects. It has its roots in a multi-criteria study done for the Coca Cola Company on their signature beverage. Later, the field of industrial ecology adopted this approach and helped establish the International Standards Organisation (ISO) 14000 series standards on LCA. The ISO framework is presented on Figure 2.

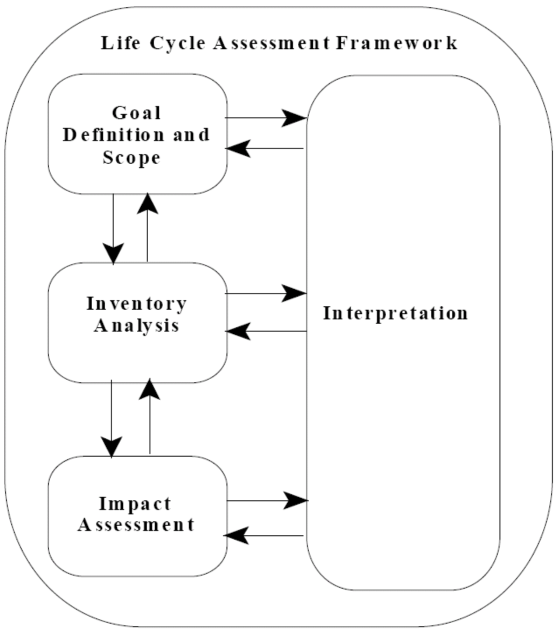


Figure 2. Phases of the life cycle assessment (EPA 2006).

© ASCE 2014

Scope definition and inventory analysis require that a system boundary be developed. In keeping with the SEIS framework, the system boundary for vegetable production involves numerous on-farm inputs and outputs. These are depicted on Figure 3.

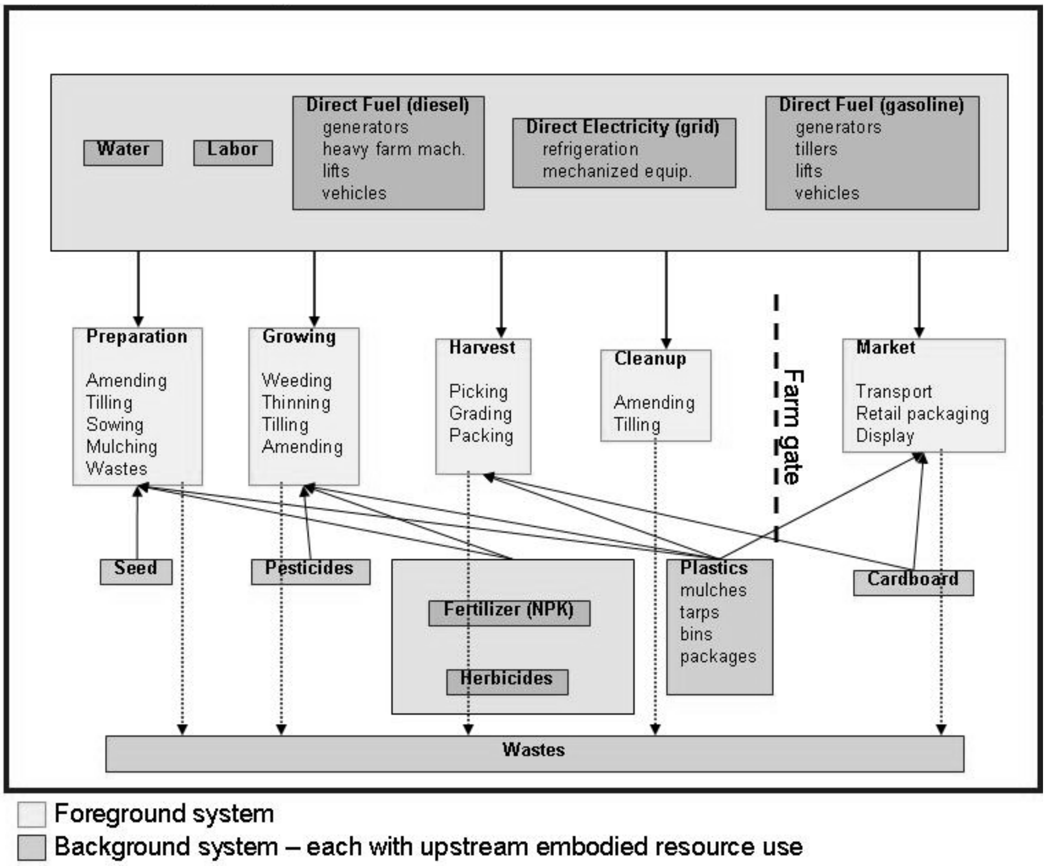


Figure 3. System boundary definition.

Using the system boundary, a comparative product life cycle assessment (LCA) is being conducted on four popular fresh vegetables (tomato, potato, carrot, and onion) grown under two different formats. The first format is characterized by the large-scale, commercial growers that supply the typical supermarket. Figure 4 depicts the locations and distances related to the four, commercially-grown vegetables.

The second format is characterized by small-scale growers (less than 1 acre) that use the land more intensely and with less mechanization. This second format is typically used by backyard gardeners, operators of neighborhood supported agriculture (NSA) and operators of some community supported agriculture (CSA) businesses.

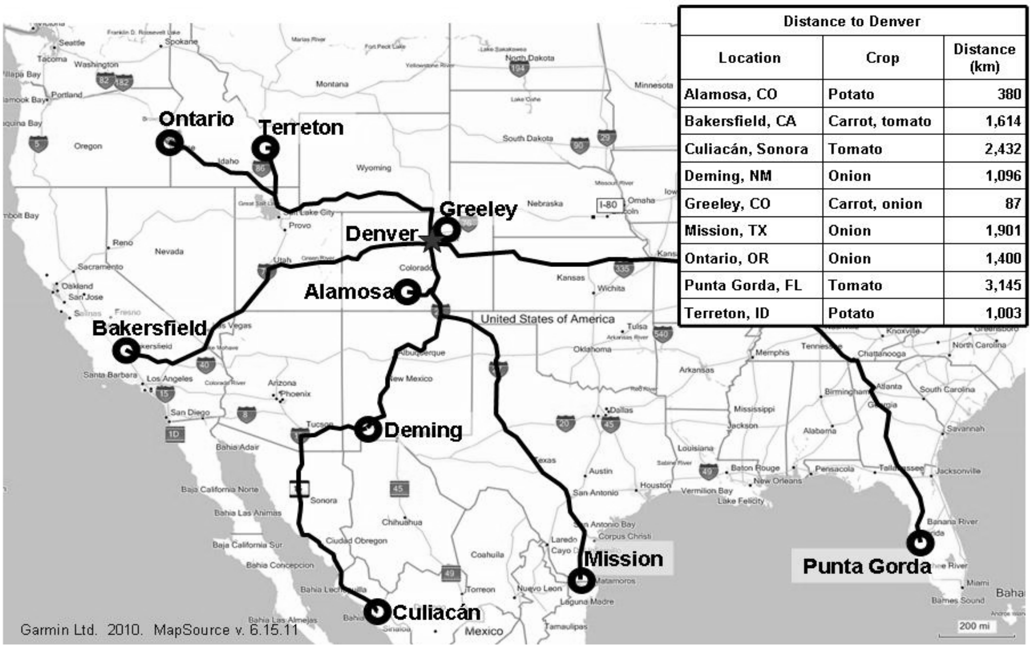


Figure 4. Regional sources of supermarket produce for Denver, Colorado.

Life cycle inventory categories include direct resource use, upstream resource use, midpoint environmental impacts, labor value, and labor hours. Inventory materials and flows were derived from published sources, such as agricultural extension services farm enterprise budgets, phone interviews with extension agents, and direct measurement (in the case of 2 growing operations in Denver, Colorado). Most of the inventory involved materials that were assumed to have properties that do not vary with location (e.g., fuel, plastics, fertilizer, etc.). However, a key contribution of this study is recognizing that the plant/soil ecosystem is influenced greatly by site-specific factors. For this reason, the inventory, ecosystem services, and impacts for soil and agricultural production were characterized using the Denitrification-Decomposition (DNDC) model (Li 2000). The complete inventory list is presented in Table 1.

Table 1. Life cycle inventory materials.

Category	Specific Material	Region	Unit
Fossil Fuel	Diesel, gasoline (well to pump – WTP)	U.S.	L
Electricity	Electricity (Scope 1,2)	eGrid region	kWh
Soil	Bagged potting soil – organic	U.S.	kg
Fertilizer	N, P, K, Zn, Mn, Mg, Cu, gypsum, sulfur, lime	U.S.	kg
Plastics (virgin resins)	HDPE, LDPE, PP, PS, PET	U.S.	kg
Paper	Cardboard	U.S.	kg
Chemicals	Herbicide, pesticide, fungicide	U.S.	kg
Water	Raw irrigation water	Site-specific	L
Water	Potable irrigation water	Denver, CO	L
Transport	Refrigerated tractor / 17-ton trailer	Varies	km
Transport	Light pickup truck	Denver, CO	km
Web Hosting	20 Mb site, 1 yr.	U.S.	year

© ASCE 2014

The life cycle assessment then converts energy use and material flows into human and environmental impacts in a life cycle impacts assessment (LCIA). For this study, the impact categories include the following:

- Energy (all non-renewable)
- Land Use (arable, non-irrigated)
- Water (all fresh water sources)
- Total carbon dioxide equivalent
- Carbon dioxide
- Nitrous oxide
- Methane
- TRACI Carcinogens
- TRACI Non-carcinogens
- TRACI Air compartment
- TRACI Water compartment
- TRACI Soil compartment
- Soil organic carbon
- Employment hours
- Laborer rate

Note: The Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) is a U.S. EPA methodology for human and ecological impacts.

The overall study is still in-progress, but the plant/soil analysis using DNDC has been completed and its preliminary results are presented in this paper. The impact categories evaluated were carbon dioxide, nitrous oxide, methane, water, and soil organic carbon. A way to present these data is through a discussion of land use change.

Land Use Change

LCIA results are interesting in and of themselves. Equally interesting is direct and indirect land use change as a result of instances of urban vegetable production. For this study, three land use conversions were defined and are depicted on Figure 5:

1. Large-scale commercial farmland – each new instance of urban gardening is assumed to displace an equal amount of commercial farmland, adjusted for differences in land productivity related to the functional unit.
2. Neglected and degraded urban areas – in the existing urban setting, a new urban garden can purpose these areas unused areas that typically have the poorest soil health and lowest soil organic carbon (SOC) levels.
3. Residential turf grass – in the existing urban setting, the demand for space for an urban garden may force conversion from turf grass.

Direct land use change occurs when conversions are examined on the same plot of land. For instance, the change that occurs from fallowing existing farmland is direct land use change. Indirect land use change occurs when land use is changed in response to a land use elsewhere. For instance, the fallowing of existing farmland is a result of putting urban land to use for vegetable production.

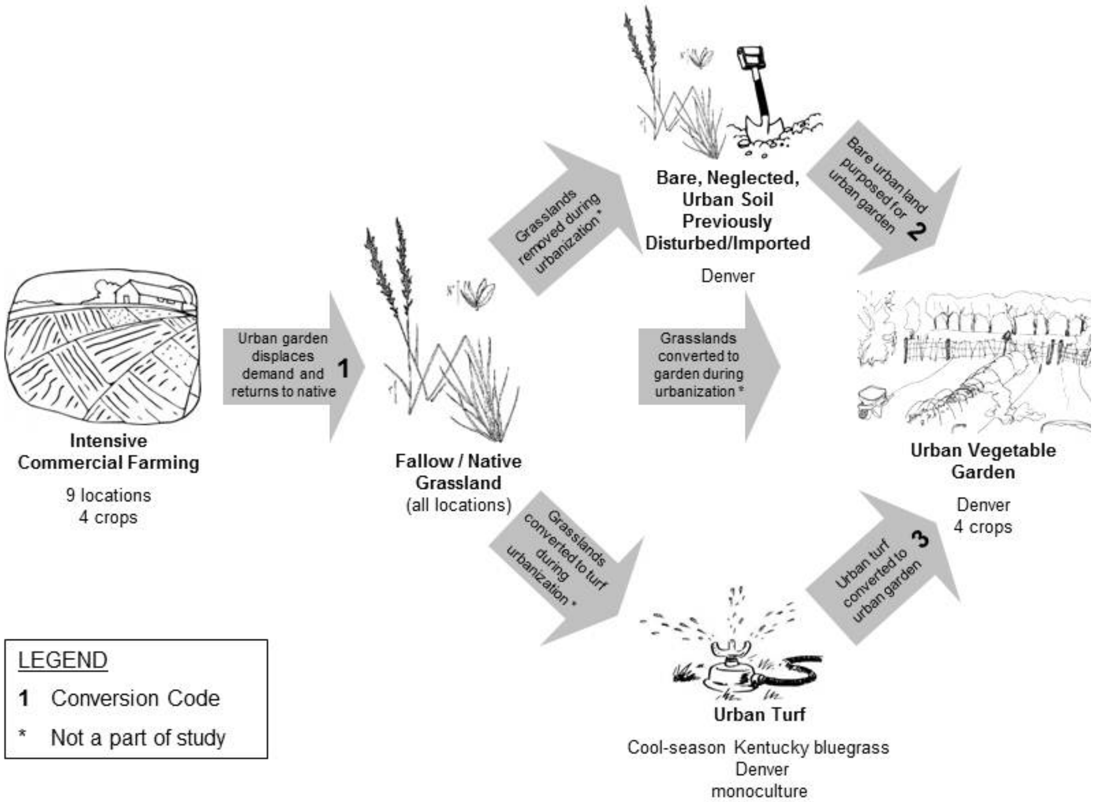


Figure 5. Land use scenarios and conversions.

Preliminary results from the DNDC model are described in terms of these three conversions. The full study will factor in other impact categories and remaining upstream materials in the inventory analysis.

Findings

The findings indicate that displacement of farmland to urban vegetable production had net benefits for all metrics. Emissions, in particular, all had sizeable reductions for urban vegetable production compared to the farmland use it displaces. The conversion from urban turf to urban garden (Conversion 3) was generally slightly more beneficial than mere conversion of vacant urban land to urban garden. Complete impacts by crop and land use change combination are shown in Table 2.

Significance

The preliminary study found that displacement of two previous urban land uses (vacant/degraded and ornamental turf grass) by instances of urban vegetable production had beneficial environmental impacts in terms of greenhouse gas emissions, water use, and soil organic carbon. Displacement of vegetable production on commercial farmland by urban vegetable production also had significant benefits. The results to-date indicate that state and local policy could remove hurdles to urban agricultural production with these data supporting claims that benefits outweigh

© ASCE 2014

costs. These results can be used in the larger life cycle assessment and land use analysis that recognize transboundary infrastructure contributions, appropriate scales and their corresponding data sets, and the full footprints of the food we eat.

Table 2. Impacts by crop and net impacts with land use change.

Constituent/Crop		Conversion 1		Conversion 2		Conversion 3		Net w/ Displace-ment	Net w/ Displace-ment
		Farm	Fallow	Degraded Urban	Urban Garden	Urban Turf	Urban Garden	Δ2 – Δ1	Δ3 – Δ1
SOC	Potato	0.016	0.017	0.014	0.016	0.032	0.033	0.002	0.001
	Carrot	0.015	0.017	0.014	0.016	0.032	0.033	0.004	0.003
	Onion	0.020	0.022	0.014	0.016	0.032	0.033	0.004	0.003
	Tomato	0.019	0.021	0.014	0.016	0.032	0.033	0.004	0.003
CO_2	Potato	1,210	100	232	954	1,547	1,160	(388)	(1,498)
	Carrot	2,572	812	232	945	1,547	1,147	(1,047)	(2,161)
	Onion	5,138	829	232	964	1,547	1,145	(3,578)	(4,712)
	Tomato	6,779	974	232	1,037	1,547	1,263	(5,001)	(6,090)
CH_4	Potato	(2.5)	(3.4)	(3.7)	(2.2)	(1.7)	(1.9)	0.5	(1.2)
	Carrot	(4.7)	(6.9)	(3.7)	(2.3)	(1.7)	(2.0)	(0.8)	(2.5)
	Onion	(3.3)	(5.2)	(3.7)	(2.7)	(1.7)	(2.4)	(0.9)	(2.6)
	Tomato	(4.3)	(5.9)	(3.7)	(2.4)	(1.7)	(2.2)	(0.4)	(2.1)
N_2O	Potato	4.16	0.04	0.06	0.09	0.22	0.24	(4.09)	(4.10)
	Carrot	7.77	0.02	0.06	0.08	0.22	0.21	(7.73)	(7.76)
	Onion	9.72	0.25	0.06	0.08	0.22	0.17	(9.45)	(9.52)
	Tomato	7.43	0.05	0.06	0.13	0.22	0.24	(7.31)	(7.36)
H_2O	Potato	730	-	-	87	938	171	(643)	(1,497)
	Carrot	764	-	-	47	938	121	(717)	(1,580)
	Onion	526	-	-	24	938	38	(502)	(1,425)
	Tomato	1,129	-	-	193	938	260	(936)	(1,807)

Notes:

H_2O Applied Water, mm/year
CH_4 Methane, kg C / ha / year
CO_2 Carbon dioxide, kg C / ha / year
N_2O Nitrous oxide, kg N / ha / year
SOC Soil organic carbon, kg C / kg soil

All values averages for 30-year, continuous cropping systems

© ASCE 2014

REFERENCES

Brett, J., et al. (2013). "A Methodology for Determining the Production Potential of Sustainable Urban Agriculture." *Journal of Agriculture, Food Systems, and Community Development* (under review).

Cuba Ministry of Agriculture (Cuba) (2008). *Agriculture in Cuba Today*. Accessed online at: http://www.cubaagriculture.com/agriculture-today.htm

Decker, E.H., et al. (2000). "Energy and Material Flow Through the Urban Ecosystem." *Annual Review of Energy and the Environment*, 25: 685-740.

Heller, M.C., and Keoleian, G. (2000). *Life Cycle-Based Sustainability Indicators for Assessment of the U.S. Food System*. Center for Sustainable Systems. Report No. CSS00-04. 6 December.

Hillman, T., and Ramaswami, A. (2010). "Greenhouse Gas Emission Footprints and Energy Use Benchmarks for Eight U.S. Cities." *Environmental Science and Technology*, 44:1902–1910.

Institute of Grocery Distribution (IGD) (2007). "Embedded Water in Food Production." Accessed online at: http://www.igd.com/index.asp?id=1&fid=1&sid=5

Intergovernmental Panel on Climate Change (IPCC) (2008). *Climate Change 2007: Synthesis Report*. *Fourth Assessment report on Climate Change*. Geneva, Switzerland.

Kloppenburg, J. Jr., et al. (2000). "Tasting Food, Tasting Sustainability: Defining the Attributes of an Alternative Food System with Competent, Ordinary People." *Human Organization*, 59:2.

Li, C.S. (2000). "Modelling trace gas emissions from agricultural ecosystems." *Nutrients Cycling in Agroecosystems*, 58: 259-276.

Ramaswami, A., et al. (2008). "A Demand-Centered, Hybrid Life-Cycle Methodology for City-Scale Greenhouse Gas Inventories." *Environmental Science & Technology*, 42:17.

Ramaswami, A., et al. (2012). "A Social-Ecological-Infrastructural Systems Framework for Interdisciplinary Study of Sustainable City Systems." *Journal of Industrial Ecology*, 16: 801–813.

U.S. Environmental Protection Agency (EPA) (2006). *Life Cycle Assessment: Principles and Practice*. EPA/600/R-06/060. May.

Weber, C.L., and Matthews, S.H. (2008). "Food-Miles and the Relative Climate Impacts of Food Choices in the United States." *Environmental Science and Technology*, 42:10, pp 3508–3513.

World Resources Institute (WRI) (2010). *Population, Health and Human Well-being — Urban and Rural Areas: Urban population as a percent of total population*. Accessed online at: http://earthtrends.wri.org/searchable_db/index.php?theme=4

© ASCE 2014

Municipal Solid Waste Incineration Bottom Ash (IBA) as Aerating Agent for the Production of Aerated Lightweight Concrete

Zhitao Chen[1], Yiquan Liu[2] and En-Hua Yang[3]

[1]School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 637820; PH +65 6592-7875; email: ztchen@ntu.edu.sg
[2]Interdisciplinary Graduate School, Nanyang Technological University, 50 Nanyang Avenue, Singapore 637820; PH: +65 6592-7875; email: liuy0102@e.ntu.edu.sg
[3]School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 637820; PH +65 6790-5291; FAX +65 6791-0676; email: ehyang@ntu.edu.sg

ABSTRACT

This study proposes an innovative approach of reutilization of municipal solid waste incineration bottom ash (IBA) for civil engineering applications. IBA is the ash residual after incineration of municipal solid waste. IBA contents a noticeable amount of metallic aluminum which leads to expansion and cracking of concrete due to the reaction between metallic aluminum in IBA and cement when used as aggregates. Instead of pre-treating IBA to remove or to immobilize metallic aluminum, this paper explores the possibility of reutilizing IBA as aerating agent to replace costly aluminum powder and as supplementary cementitious material to partially replace cement in the production of aerated lightweight concrete. Compressive strength and dry density tests are carried out to evaluate the mechanical and physical properties of the resulting aerated lightweight concrete. The pore structure is analyzed through microscope and image analysis method. The results show that IBA can be used as aerating agent to produce aerated lightweight concrete. There is an obvious positive correlation between compressive strength and dry density of the resulting material.

Keywords: IBA; aerated concrete; pore structure; mechanical properties

INTRODUCTION

Incineration of municipal solid waste produces two kinds of by-products - incineration bottom ash (IBA) and incineration fly ash (IFA). Scarcity of land in municipal area and high expenditure for waste disposal make waste reutilization a viable solution. IBA occupies 80% of total incineration residues (Chimenos et al., 1999) and is classified as a non-hazardous waste according to the European Waste Catalogue (Filipponi et al., 2003) as it contains much less leachable heavy metals and highly toxic organic substances, such as dioxins, as compared to IFA (Ferreira et al., 2003). In addition, the chloride content in IBA is much less than that in IFA (Lam et al., 2012). All these make IBA a potential waste for recycling and reutilization for civil engineering applications.

Several studies have been carried out to evaluate the potential use of IBA for civil engineering applications (Jurič et al., 2006; Lam et al., 2012). Current state-of-the-art reuses IBA for road construction, embankment, pavement, aggregate and filler for concrete. One major drawback, however, hinders the wide application and acceptance of IBA as it has been reported that the use of IBA can lead to expansion and cracking of concrete due to the reaction between metallic aluminum in IBA and cement hydration product of calcium hydroxide (Pera et al., 1997).

With the increasing growth of incineration of household waste, more and more aluminum is retained in municipal solid waste incinerator bottom ash (Hu and Rem, 2009). Unlike ferrous metal, which could be easily extracted from bottom ash, the recovery efficiency of non ferrous metal is low. Traditional eddy current method shows an average recovery efficiency of 30% of the aluminum fed into the furnace of the incineration plant (Grosso et al., 2011), which means that most aluminum still remain in IBA. Especially for fine IBA particles, the recovery ratio is nearly zero (Biganzoli et al., 2013). Furthermore, many incineration ash treatment plants have not installed non ferrous metal recovery set-up due to cost issue and resulted in full aluminum remaining in IBA. In a word, IBA results in great lost aluminum resource and constrains aluminum recycle process.

Aerated concrete is a lightweight material in which a uniform cellular structure of air voids distributed throughout a matrix of cement paste of mortar. With extremely low density (500 kg/m^3) and thermal conductivity (0.1W/m·K), aerated concrete is an idea material for thermal insulation and sound-proofing. Aerated concrete can be used for floors, trench fills, roof insulation and other insulating purposes, as well as to make masonry units. The introduction of gas in aerated concrete is achieved usually by the inclusion of finely divided aluminum powder. The aluminum reacts with the soluble alkalis in the cement slurry to generate small bubbles of hydrogen.

In this paper, incineration bottom ash containing aluminum was used as aerating agent to replace aluminum powder, which could reduce the cost greatly. Typical mix proportion of autoclaved aerated concrete can be found in Table 1. From the following cost data of Table 1, aluminum powder used in the aerated concrete has the most expensive unit price. And though its usage amount is the least, its whole cost still occupies nearly one tenth of the total cost.

Table 1. Typical mix proportion and cost structure of autoclaved aerated concrete

Material	Mix proportion (kg/m^3)	Unit price (S$/ton)	Cost (S$/m^3)	Cost ratio
Cement	49	152	7.4	26%
Sand	490	14	6.9	25%
Lime	133	80	10.6	38%
Gypsum	28	20	0.6	2%
Aluminum powder	0.46	5200	2.4	9%
		Total	27.9	100%

EXPERIMENTS

Materials and mix design. The raw materials for preparing aerated lightweight concrete included P·I 42.5 cement (C), grinding IBA, sand (S) and sodium hydroxide solution. The original IBA was collected from Keppel Seghers Tuas Waste-to-Energy incineration plant, Singapore. The IBA was firstly dried and subsequently ground by ball milling until the average particle size was around 40 microns. The main oxide composition of the IBA was determined by x-ray fluorescence (XRF) as shown in table 2. As can be seen from the table, the major components include SiO_2, CaO, Fe_2O_3 and Al_2O_3, which exceed 80% of the total weight of IBA. The content of heavy metal oxide ranges from 0.01% to 1%. In addition, the Singapore local IBA is rich in a certain amount of metallic aluminum, which can be used to replace expensive aluminum powder which was generally used as aerated agent. The sodium hydroxide solution was used in the case of cement with insufficiently high alkalinity to supplement alkali required for gas generating.

Table 2. Chemical compositions of IBA

Oxide	Content (%)	Oxide	Content (%)
SiO_2	32.75	K_2O	1.24
CaO	29.06	ZnO	0.81
Fe_2O_3	10.02	CuO	0.31
Al_2O_3	8.57	Cr_2O_3	0.22
P_2O_5	4.77	MnO	0.15
SO_3	3.01	PbO	0.12
Na_2O	2.87	SrO	0.10
MgO	1.75	NiO	0.06
TiO_2	1.57	ZrO_2	0.01

The mix proportions of aerated lightweight concrete are showed in Table 3. For all mixes, the binder to sand ratio was 1:1. In group A and B, 25% of cement was replaced by IBA. In mix C1 and C2, the replacement ratio was further increased to 40% and 60%, respectively. Sodium hydroxide solution with molarity of 0.01mol/l, 0.1mol/l and 1mol/l was prepared and used in group A and C, while tap water without sodium hydroxide was used in group B. A liquid to solid (L/S) of 0.175 was adopted in group A and B. A higher liquid to solid ration of 0.35 was adopted in group C to maintain adequate workability since IBA absorbed much more water as compared to cement.

Sample preparation. A planetary mixer was used to prepare the mortar. Firstly, the cement, IBA and sand were dry mixed for approximately 1-2 minutes, followed by the addition of alkaline solution or water and mixed for another 2 to 3 minutes. The fresh mixture was cast into 50 mm cubic molds and vibrated for 30 seconds. The molds were covered with plastics to prevent water evaporation and the specimens with mold were cured in elevated temperature of 80°C or room temperature of 20℃ after casting. The elevated temperature curing was taken to accelerate the hardening

© ASCE 2014

of cement and the reaction of aluminum with alkaline. Specimens were demolded after 72 hours and cured in water for 28 days until test.

Table 3. Mix proportions and properties of aerated lightweight concrete

Mix No.	C	IBA	S	L/S	Solution	Molarity (mol/l)	Curing Condition	Dry density (kg/m^3)	f_c (MPa)
A1	4	1	5	0.175	NaOH	1	80°C	1324.0	5.7
A2	4	1	5	0.175	NaOH	0.1	80°C	1443.7	12.5
A3	4	1	5	0.175	NaOH	0.01	80°C	1512.0	16.0
B1	4	1	5	0.175	Water	-	80°C	1553.6	19.5
B2	4	1	5	0.175	Water	-	20°C	1604.8	21.5
C1	3	2	5	0.35	NaOH	1	80°C	1056.4	2.7
C2	2	3	5	0.35	NaOH	1	80°C	931.6	1.5

Test methods. Dry density was defined as a ratio of the dry weight to the volume of each specimen. The specimens were dried in oven at 105℃ for at least 24 hours. The weight and volume of the dry specimen were recorded to determine the dry density.

Compression tests were conducted using 50 mm cube specimen at the age of 28 days. The loading rate was 0.50 mm/min and only peak loads were recorded. Each data point was the average of three specimens.

To evaluate the macro-porosity of aerated lightweight concrete, image of the cross-section of the specimen (12 × 9 mm^2) was captured by means of the *Nikon* SMZ745T optical microscope. The photo was post-proceeded into a binary image for quantitative measurement of the macro-porosity of the cross-section as shown in Figure 1.

Scanning electron microscope (SEM) technique was conducted by using JEOL-7400F field-emission scanning electron microscope to examine the microstructure of aerated lightweight concrete.

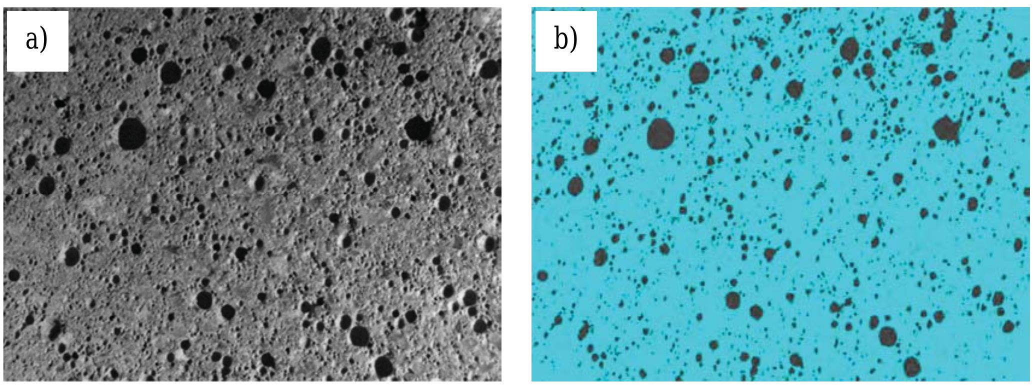


Figure 1. Example of optical image (a) and binary image (b) of pore structure in aerated lightweight concrete (pores in black).

© ASCE 2014

RESULTS & DISCUSSION

Strength and density. The compressive strength and dry density are summarized in Table 3. As can be seen, the dry density of the resulting aerated lightweight concrete ranges from 900 kg/m^3 to 1,600 kg/m^3 with compressive strength between 1.5 MPa and 21.5 MPa. The general trend shows a positive correlation between the compressive strength and the density of aerated lightweight concretes. As shown in Figure 2, the compressive strength of aerated lightweight concrete increased with the increase of dry density, which satisfied an exponential correlation in the whole range.

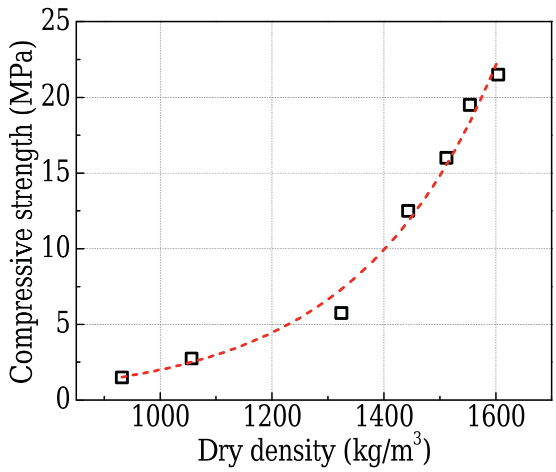


Figure 2. Compressive strength versus density of aerated lightweight concrete.

Figure 3 shows the effect of alkali molarity (Figure 3a) and IBA content (Figure 3b) on the properties of aerated lightweight concrete. As can be seen, the compressive strength as well as the dry density decreases with the increase of alkali molarity or IBA content. Higher alkali molarity greatly promotes hydrogen generation from IBA resulting in more aeration and lower density and compressive strength. Similarly, higher IBA content generates more hydrogen which reduces the density of samples C1 and C2. In addition, IBA itself has lower specific gravity than cement. The inclusion of higher dosage of IBA naturally reduces the dry density of the resulting material.

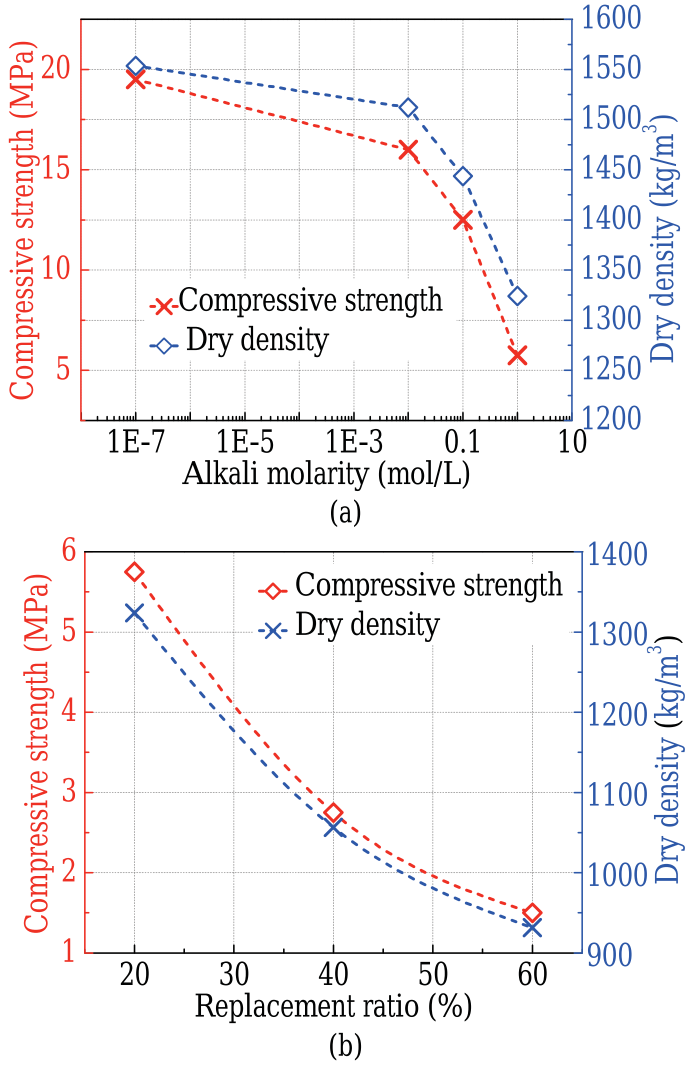


Figure 3. Effect of alkali molarity and IBA replacement ratio on the compressive strength and dry density of aerated lightweight concrete: (a) alkali molarity; (b) IBA replacement ratio.

Macro-porosity. The macro-porosity of aerated lightweight concrete in this research ranges from 15% to 40%. Figure 4 shows the effect of macro-porosity on the dry density and compressive strength of each mix of aerated lightweight concrete. As can be seen from the figure, both dry density and compressive strength decrease with the increase of macro-porosity. Decrease of dry density as well as compressive strength mainly results from the increase of macro-porosity. Both suitable alkali molarity and proper dosage of IBA are the critical factors for obtaining better pore structures and further for improving the mechanical and physical properties of aerated lightweight concrete.

© ASCE 2014

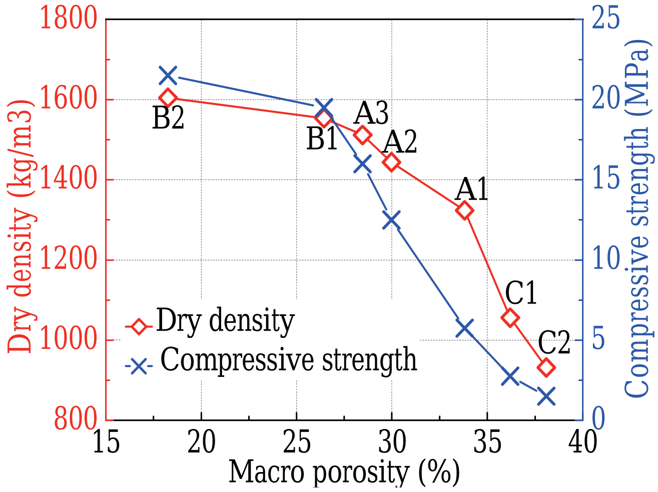
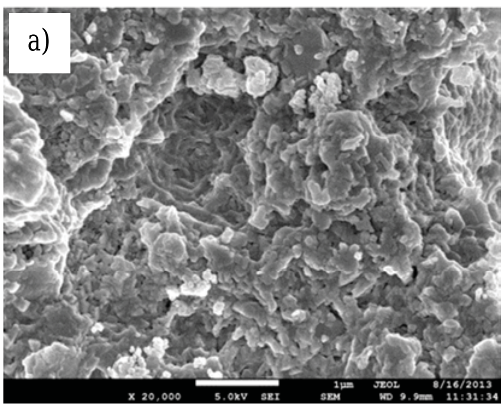
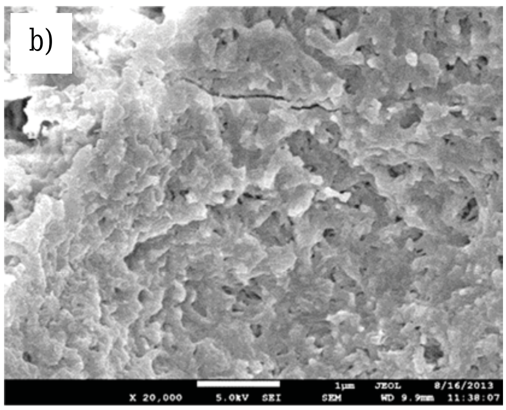


Figure 4. Effect of macro-porosity on dry density and compressive strength of IBA aerated lightweight concrete.

SEM investigation. Figure 5 shows the microstructure of aerated lightweight concrete prepared with tap water (denoted by TW) and sodium hydroxide solution (denoted by NH) curing in oven at 80℃. As can be seen, matrix of the TW sample (Figure 5a) has a denser microstructure as compared to that of the NH sample (Figure 5c). This is mainly due to accelerated hydration when sodium hydroxide is used in cement (Jawed and Skalny, 1978). Coarse calcium silicate hydrates and large amount of ettringite are formed at early age resulting in a loose microstructure (Jawed and Skalny, 1978). In addition, crystal structure is found in the wall of macro-pores of the NH sample (Figure 5d). The addition of sodium hydroxide increases the concentration of hydroxyl ions in the pore solution which depresses the solubility of Ca^{2+} ions (Chen and Lu, 1993). As a result, calcium carbonate and/or calcium hydroxide may precipitate on the wall of macro-pores as shown in Figure 5d.





© ASCE 2014

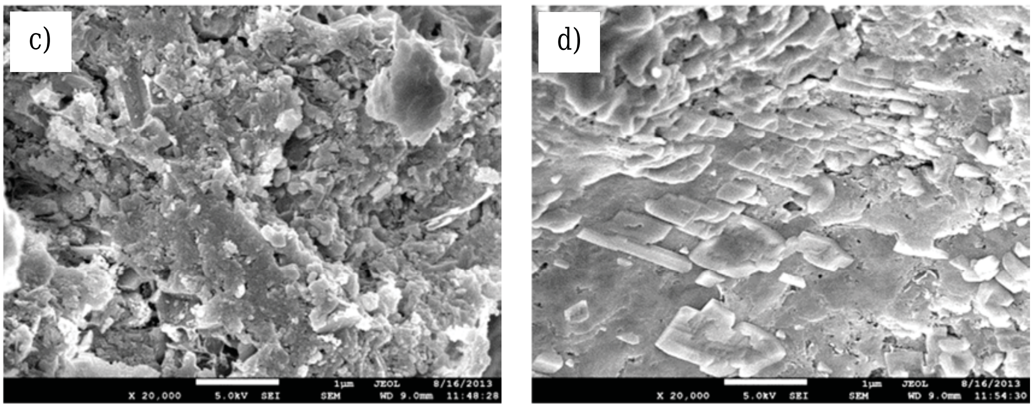


Figure 5. Typical SEM images of IBA aerated lightweight concrete prepared with (a) tap water, matrix; (b) tape water, wall of macro-pore; (c) NaOH solution, matrix; (d) NaOH solution, wall of macro-pore.

CONCLUSIONS

In this study, municipal solid waste incineration bottom ash (IBA) was used as the aerating agent to replace aluminum powder for the production of aerated lightweight concrete. The effects of IBA replacement ratio and alkali molarity of solution on the mechanical and the physical properties of aerated lightweight concrete were investigated.

It was found that there is a positive correlation between the compressive strength and the dry density of the resulting aerated lightweight concrete. The compressive strength and dry density decrease with the increase of IBA replacement ratio and/or molarity of alkali solution. Increase of macro-porosity is the primary reason for the reduction of compressive strength and dry density in IBA aerated lightweight concrete. The addition of higher molarity of alkali solution accelerates cement hydration and result in loose microstructure. This is another cause which leads to change of mechanical and physical properties of the resulting aerated lightweight concrete.

REFERENCES

Biganzoli, L., Ilyas, A., Praagh, M. V., Persson, K. M., and Grosso, M. (2013). "Aluminium recovery vs. hydrogen production as resource recovery options for fine MSWI bottom ash fraction." *Waste Management*, 33(5), 1174-1181.

Chimenos, J. M., Segarra, M., Fernández, M. A., and Espiell, F. (1999). "Characterization of the bottom ash in municipal solid waste incinerator." *Journal of hazardous materials*, 64(3), 211-222.

Chen, X., Lu, C. (1993). "Effect of alkali on hydration process and properties of cement." *Journal of the Chinese ceramic society*, 1(4), 301-308.

Ferreira, C., Ribeiro, A., and Ottosen, L. (2003). "Possible applications for municipal

© ASCE 2014

solid waste fly ash." *Journal of Hazardous Materials*, 96(2-3), 201-216.
Filipponi, P., Polettini, A., Pomi, R., and Sirini, P. (2003). "Physical and mechanical properties of cement-based products containing incineration bottom ash." *Waste Management*, 23(2), 145-156.
Grosso, M., Biganzoli, L., and Rigamonti, L. (2011). "A quantitative estimate of potential aluminium recovery from incineration bottom ashes." *Resources, Conservation and Recycling*, 55(12), 1178-1184.
Hu, Y., and Rem, P. (2009) "Aluminium alloys in municipal solid waste incineration bottom ash." *Waste Management and Research*, 27(3), 251-257.
Jawed, I., and Skalny, J. (1987). "Alkalies in cement: a review: II. Effects of alkalies on hydration and performance of Portland cement." *Cement and Concrete Research,* 8, 37-52.
Jurič, Bernardka, Lucija Hanžič, Radomir Ilić, and Niko Samec. (2006). "Utilization of municipal solid waste bottom ash and recycled aggregate in concrete." *Waste Management*, 26(12), 1436-1442.
Lam, C. H. K., Ip, A. W. M., Barford, J. P., and McKay, G. (2012). "Use of incineration MSW ash: A review." *Sustainability*, 2, 1943-1968.
Pera, J., Coutaz, L., Ambroise, J., and Chababbet, M. (1997). "Use of incinerator bottom ash in concrete." *Cement and Concrete Research*, 27(1), 1-5.

© ASCE 2014

Performance Assessment of Sustainable Composite Roofing Assemblies Using Experimentation

V V Sakhare[1]; S P Raut[2]; S A Mandavgane[3]; R V Ralegaonkar[4]

[1]Research Scholar, Department of Civil Engineering, VNIT, Nagpur 10, Maharashtra, India; PH (+91-7875015665); email:vishakha.sakhare@gmail.com
[2]Research Scholar, Department of Civil Engineering, VNIT, Nagpur-10; and Assistant Professor, Department of Civil Engineering, YCCE, Maharashtra, India; PH (+91-9422826611); email: sprce22@gmail.com
[3]Associate Professor, Department of Chemical Engineering, VNIT, Nagpur-10, Maharashtra, India; PH (+91-9422301167); email: rvralegaonkar@vnit.ac.in
[4]Associate Professor, Department of Civil Engineering, VNIT, Nagpur-10, Maharashtra, India; PH (+91-9823128835); email:sanvan28@yahoo.com

ABSTRACT

Over the hot climatic zones all buildings which have roof directly exposed to sun imparts significant heat gain inside the buildings. The problem of excessive cooling demand inside the building can significantly be addressed using reflecting and insulating materials as a retrofitting solution. The present paper elaborates application of sustainable reflecting-cum-insulating (R-I) materials over the flat concrete roof surface for reducing the impact of heat gain inside the buildings. The composite R-I assemblies used for thermal performance assessment includes aluminum sheet, broken glazed tiles, expanded polystyrene (construction waste), sawdust (industrial waste), mineral fiber board (recycled content 38%) and false ceiling panels (recycled content 90%). These materials were placed in two different combinations as a composite heat barrier assembly for exposed concrete roof of the two model rooms in an educational building over the considered geographic location. In comparison to the untreated concrete slab, the applied composite R-I assemblies resulted in an overall increase in thermal resistance of the first and second assembly by 1.9 and 3.9 times respectively. Over a period of a year under experimentation, the first and second retrofitted assembly resulted in 6% and 19% reduction in surface temperature respectively. The considered R-I materials for the experimentation have proved to be thermally efficient, lighter and cost effective solution for energy conservation inside the buildings. The R-I product can further be applied on larger roof areas by the designers to reduce the cooling load of the built environment as well as increase the occupants comfort over the local climatic zone.

Keywords: sustainable reflecting-cum-insulating (R-I) assembly, concrete roof, temperature, thermal resistance.

INTRODUCTION

Thermal insulation plays significant role in reducing cooling requirement inside a building in hot climate. Improved thermal insulation of the building results in better comfort and conservation of energy that is otherwise required for excessive cooling.

© ASCE 2014

In a typical commercial establishment, the space conditioning accounts for 50-70% of the total energy used (Iosifides, 1998). With the right materials to be used as thermal barriers in buildings has helped in reducing energy consumptions having a deep impact on the environment as a whole. The construction practices adopted mainly involve concrete as the roofing element which is noted for its high thermal conductivity. The exposed roof surfaces absorb solar heat that will input continuous heat inside the building and will add to the cooling load.

Thermal barrier for building roof is generally installed either as over or under deck insulation. Al-Homoud (2005) presented an overview of the basic principles of thermal insulation along with detailed investigations on the most commonly used building insulation materials and their performance characteristics. Alvarado *et al*. (2009) investigated the thermal effects of newly designed passive cooling systems on concrete roofs in existing buildings. Each tested passive cooling system consists of a combination of materials that can reduce heat load in buildings. Commercially available materials such as aluminum-1100 and galvanized steel were used as radiation reflectors; and polyurethane, polystyrene, polyethylene, and an air gap was used as insulation. Double envelope constructions were used in constructions with double-wall systems and very limited literature exists on ventilated roof constructions. Double envelope roof constructions were investigated either as a preheating system of the external air (Serres, 1997) or as a double shell system in tilted roofs. In this case, ambient air passes through the air gap that incorporates a wet surface into its lower part, becomes cooler through evaporation and thus, lowers the surface temperature of the internal part of the roof (Manzan, 2000). Heat-insulating materials provided an effective means of reducing the apparent density and improving the refractory properties of manufactured components. Materials of natural occurrence viz., vermiculite, diatomite, infusorial earth, perlite, as well as synthetic materials - hollow microspheres obtained by sputtering of high-melting oxides such as Al_2O_3, mullite, and spinel were used as porous fillers (Suvorov, 2003; Abramova, 1990; Stelmah, 1990; Jungk, 1997). However, the hollow spheres are costly products and are normally used to fabricate special high-temperature heat insulators (Permikina, 1991). Al-Malah *et al*. (2007) focused on the formulation of polyester–clay composite as an insulating material that gives the best thermal and mechanical properties. Korjenic *et al*. (2011) developed, optimized, and observed the behavior of thermally insulating materials composed of renewable raw material resources originating from agricultural sources which could be used in new building structures and for renovating the existing structures. The rooftop lawn resulted in a reduction in the air conditioning load of buildings and contributed to the mitigation of the heat island phenomenon. Hasegawa and Konna (2001) carried out an analysis on the thermal effect of the rooftop spraying system on slant roof. Tanabe *et al*. (2000) had done a field study on a rooftop spraying system. The effect of roof spraying contributed to room temperature reduction in the summer season. Ishihara *et al*. (1996) carried out an experimental study on thermal characteristics and water performance of rooftop lawn. Hoyano *et al*. (2000) clarified the indoor thermal control effect of rooftop lawn planting with thin soil layer on a wooden building. Al-Sanea (2002) evaluated and compared the thermal performance of building roof elements subject to steady periodic changes in ambient temperature, solar radiation

© ASCE 2014

and nonlinear radiation exchange. An implicit, control volume finite-difference method was developed and applied for six variants of a typical roof structure used in the construction of buildings in Saudi Arabia. Tsang & Jim (2011) developed a theoretical basis of green roof thermal performance and applied theoretical calculations to estimate the effectiveness of green roof thermal performance and associated energy saving.

From the reviewed literature, it is significant that the substantial amount of energy is consumed for the space conditioning. It was also observed that the appropriate design of thermal barrier over the roof surfaces plays a significant role to improve the thermal performance inside the buildings. Application of appropriate, reflecting-cum-insulating material either over or under the roof slab is an effective solution to conserve the energy and the cost of operation (cooling load) as well. A very little research had revealed the application of sustainable materials for the reduction of overheating of the buildings. The present paper focuses on analyzing the behavior of roof surface temperature due to application of sustainable composite roofing assemblies for reducing cooling load of the built environment by experimentation. The techno-economic feasibility of considered composite roofing assemblies is also carried out.

METHODOLOGY

In order to assess the performance of considered sustainable composite roofing assemblies the following stepwise methodology was adopted.

- The ambient temperature data over the specific geographic location was collected for the study of temperature variations.
- The volume of the built room under the study was estimated.
- Locally available low cost, sustainable materials were identified.
- The thermal properties of the used reflecting-cum-insulating (R-I) materials were assessed.
- Two different combinations from the identified sustainable materials as a composite heat barrier assembly were retrofitted on the exposed concrete roof of the two model rooms.
- The composite R-I assemblies retrofitted over the roof of model rooms were analyzed further experimentally and statistically (using the area under the curve approach) to check the performance of thermal barrier at various retrofitted layered assemblies.
- The R-I combinations were checked and compared for economic viability.

© ASCE 2014

EXPERIMENTATION

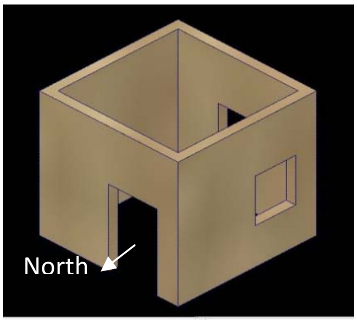


Figure 1. Model room 1

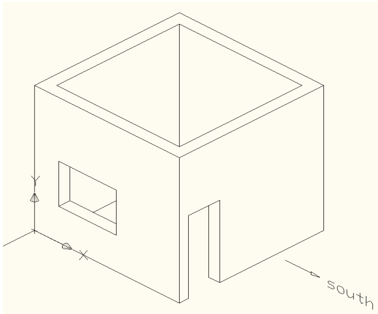


Figure 2. Model room 2

Figure 3. Temperature gun

Two non air conditioned model rooms of dimension 3.2X3.2X4.0 cum were selected for experimentation at Visvesvaraya National Institute of Technology, Nagpur (Latitude: 21°06' N, Longitude: 79°03' E, Elevation: 310 m.), India (Figure 1 & Figure 2). The geographic location has varying seasonal conditions as summer (February-May), rainy (June-September), winter (October-January). The monthly average ambient temperature and relative humidity are in the range of 27-41°C and 24-70% respectively (Krishnan, 2007). The average wind speed is 44 m/s (IS 875: Part III) and the average solar radiation is 18.34 $MJm^{-2}day^{-1}$ (Solar radiation handbook) over the considered geographic location. The roof of the model rooms which were directly exposed to the sun were made up of conventional concrete slab (0.15 m. Thick). The vertical walls were made up of burnt clay bricks. Model room 1was having a wooden door (0.9X2.1 m.) on North facing wall and a window (1X1.2 m.) on the West and South wall (Figure 1), while model room 2 was having a wooden door (0.9X2.1 m.) on south facing wall and a window (1X1.2 m.) on the west wall (Figure 2).

With the help of temperature gun (Figure 3) the internal (I) exposed surfaces (I-East, I-South, I-West, I-North, I- untreated concrete roof, I-Floor) temperature data were recorded (Figure 4) and used further for analyzing the thermal behavior of construction elements. The monitoring was done on alternate hourly basis during working hours (8 am to 6 pm) over three months of duration (September–November 2010). The temperature data were recorded on four corners as well as the center of all the surfaces and the average values were used for the analysis. It is evident from Figure 4 that roof surface is the primary concern due to which excess heat is there in the model room.

To reduce the temperature of the untreated roof, it must be protected with appropriate sustainable composite roofing assembly which intern reduces the cooling load. In order to apply sustainable composite roofing materials locally available raw materials were identified.

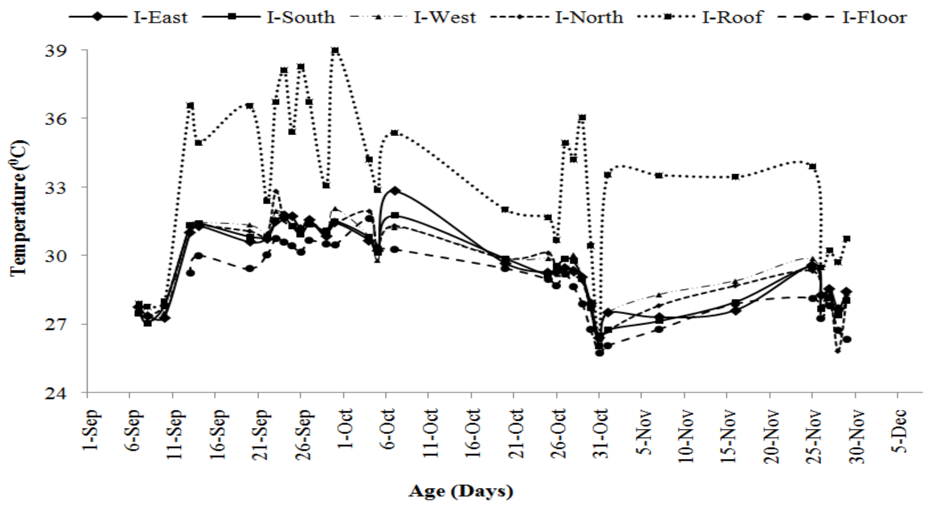


Figure 4. Variation of indoor surface temperature without insulation

Application of sustainable composite roofing materials

For the R-I composite assembly identified locally available sustainable materials were used. The composite assembly (Figure 5a) of expanded polystyrene, mortar saw dust and reflectors with aluminum foil (reflectivity (r) 0.80, (SP: 41, 1987)) were applied over the RCC roof surface of model room 1. The commercially available aluminum was retrofitted with expanded polystyrene and sawdust as the over deck solution (Figure 5b). The false ceiling material (12 mm thick, 90% recycled paper mill waste) with thermal conductivity (k) as 0.3 W/m K (Raut *et al.*, 2012) was applied as under deck solution (Figure 5c).

The composite assembly (Figure 6a) of broken glazed tiles (reflectivity (r) 0.35, (SP: 41, 1987)), expanded polystyrene, sawdust and the commercially available mineral fiber board (false ceiling material, R=0. 25 m^2 K/W, 14 mm thick, 38% recycled content) was applied over the RCC roof surface of the model room 2. The broken glazed tiles were retrofitted as over deck solution (Figure 6b). The commercially available mineral fiber board was retrofitted with expanded polystyrene and sawdust composite as under deck solution (Figure 6c).

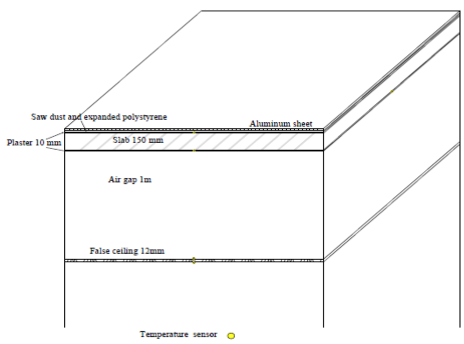


Figure 5 (a). Details of assembly 1 composition

Figure 5 (b). Over deck retrofitting

Figure 5 (c). Under deck retrofitting

Figure 5. Assembly 1: Aluminum sheet + expanded polystyrene + saw dust + false ceiling developed from industrial waste

A non-ventilated air cavity of 1 m. (Thermal conductance (C_a) as 6.22 W/m²K, (SP: 41, 1987)) was maintained between concrete roof slab and the false ceiling of both the assemblies (Figure 5a & Figure 6a). Experimental temperature log for various surfaces of the designed composite roof were recorded with the help of contact type temperature sensors & a data logger (Figure 7).

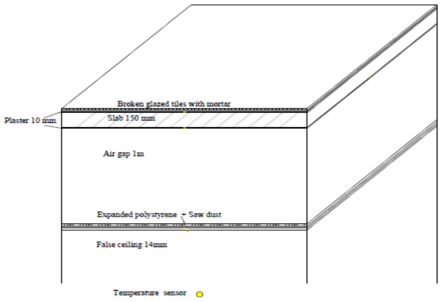


Figure 6(a). Details of assembly 2 composition

Figure 6 (b). Over deck retrofitting

Figure 6 (c). Under deck retrofitting

Figure 6. Assembly 2: Broken glazed tiles +expanded polystyrene + saw dust + false ceiling of mineral fiber board

© ASCE 2014

Figure 7. Temperature data logger

RESULTS AND DISCUSSION

Performance assessment of sustainable composite roofing assemblies

The thermal properties (thermal conductivity, density, and specific heat) of various materials used for the development of composite roof slab (Figure 5a & Figure 6a) were studied further (Table 1) (SP: 41, 1987). The overall thermal resistance of untreated concrete roof slab in combination with the external and internal plaster, including film coefficients was estimated as 0.28 m^2 K/W. In order to evaluate the effectiveness, the overall thermal resistance for the applied sustainable R-I combination was estimated using equation 1. Total thermal resistance for assembly 1 and assembly 2 was estimated as 0.55 m^2 K/W and 1.093 m^2 K/W respectively. Thus, in comparison to the untreated concrete slab, the applied composite roofing materials resulted in overall increase in thermal resistance of first and second assembly by 1.9 and 3.9 times respectively.

Table 1. Thermal properties of the materials used for retrofitting

Sr No	Materials with thickness (L) in m.	Thermal conductivity, *k* (W/mK)	Density (kg/m3)	Specific heat (J/kgK)	Position in assembly
1	Aluminum (0.02005)	0.268	1900	800	Reflecting material - Over deck
2	Glazed tiles (0.006)	1.500	1900	800	
3	Industrial waste panels (0.012)	0.300	670	904.41	False ceiling material - Under deck
4	Mineral fiber board (0.014)	0.057	-	-	
5	Expanded polystyrene + sawdust (0.015)	0.038	16	1340	Over deck or Under deck
			188	1000	
6	Mortar (0.005)	0.719	1648	920	Over deck
7	Air gap (1)	C_a=6.22 W/m^2K	-	-	Between concrete slab and false ceiling
8	External plaster (0.010)	0.721	1762	840	-

© ASCE 2014

9	Concrete slab (0.150)	1.580	2300	1000	-
10	Internal plaster (0.010)	0.721	1762	840	-

Total thermal resistance (R_T) of overall R-I composite assembly

$$R_T = \left[\sum_{i=1}^{7}\left(\frac{L}{K}\right)_i\right] + \frac{1}{C_a} + \frac{1}{f_i} + \frac{1}{f_o} \quad \ldots\ldots (1)$$

Where; Inside film coefficient; f_i= 9.36 W/m^2K

Outside film coefficient; f_o=19.86 W/m^2K …..(SP: 41, 1987)

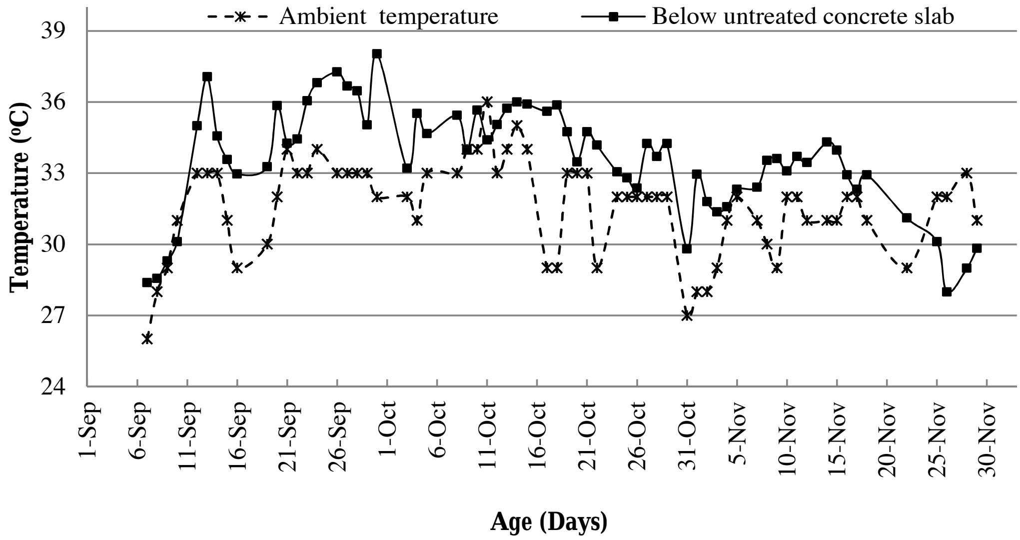


Figure 8. Temperature variations below untreated concrete slab

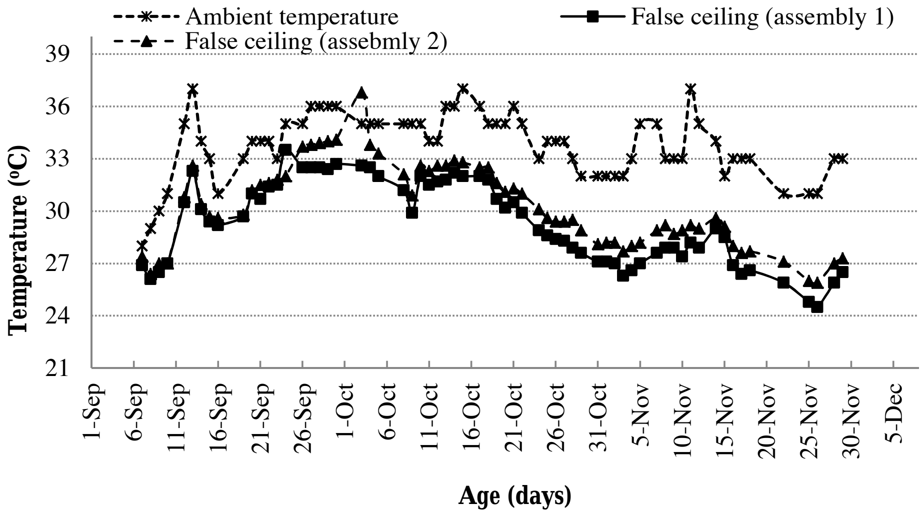


Figure 9. Temperature variations below false ceiling of both the assemblies

In order to analyse the temperature variations of the assembly below the concrete slab (untreated & treated) and at false ceiling bottom surface with respect to ambient temperature, hourly temperature data were recorded over the period of September–

November (Figure 8 and Figure 9). Using area under the curve approach, the estimated areas under untreated concrete slab and false ceiling (bottom) of assembly 1 and assembly 2 were estimated as 2783 sq. units, 2506.9 sq. units and 2427 sq. units respectively. Thus, when compared with internal untreated concrete roof slab, the average temperature reduction at the bottom surface of false ceiling is 11% and 13% for assembly 1 and assembly 2 respectively.

Further, for the retrofitted R-I assembly the temperature log was recorded for a year (July 2011- July 2012) over the various salient composite roof surfaces (Figure 5a & Figure 6a) and resulted in further temperature control in the built environment of model rooms (Figure 10 & Figure 11). For assembly 1, using the area under the curve approach the area under the internal treated concrete slab is 12056 sq. units and internal exposed false ceiling bottom surface was found to be 11355 sq. units. Thus, there is 709 sq. units (6%) reduction in surface temperature as compared to treated concrete slab.

Using the similar (area under the curve) approach for assembly 2, the area under the internal exposed composite false ceiling (saw dust, expanded polystyrene and mineral fiber board) bottom surface was found to be 10919 sq. units and of treated concrete slab below glazing tiles is 13524 sq. units. Thus, there is 2605 sq. units (19%) reduction in surface temperature as compared to concrete slab. In turn, it will help to reduce the cooling load of the built environment.

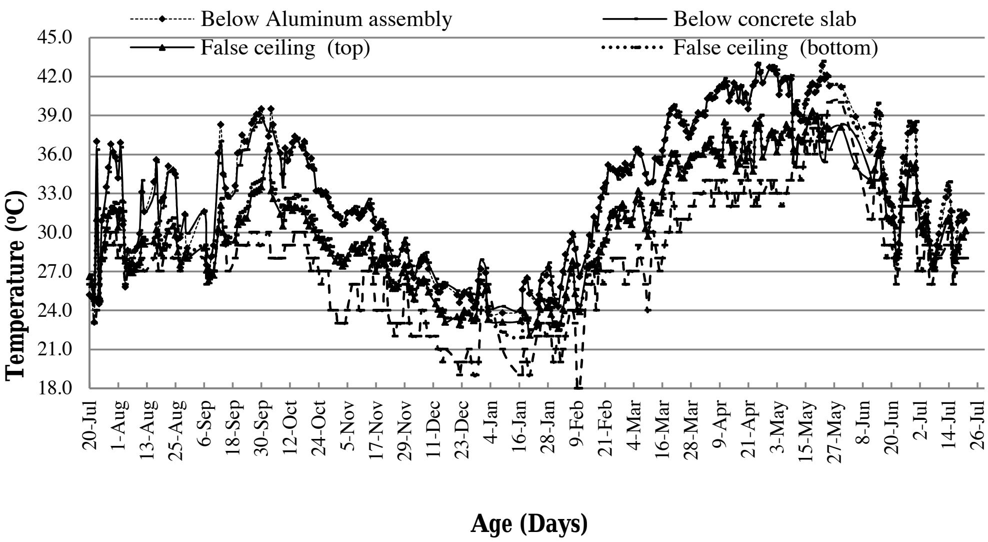


Figure 10. Overall temperature variations of assembly 1

© ASCE 2014

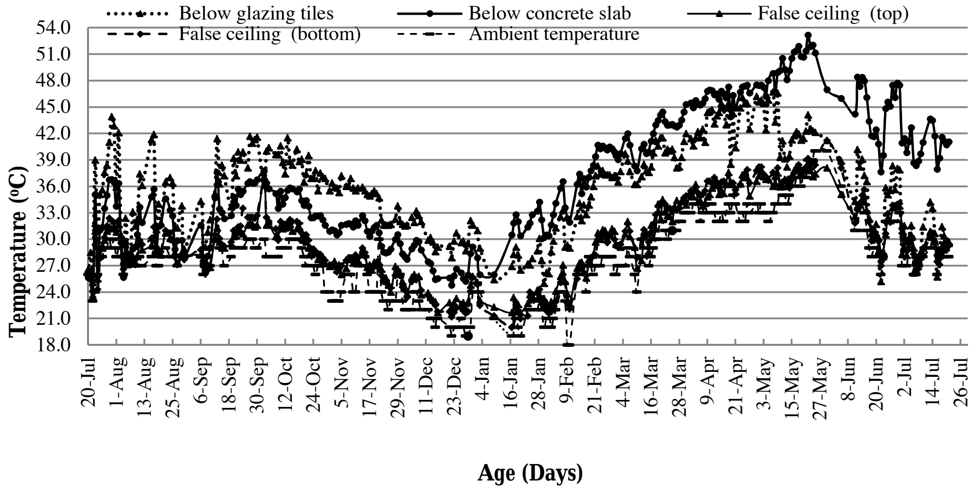


Figure 11. Overall temperature variations of assembly 2

Economic feasibility of considered composite roofing materials

The developed R-I product from aluminium sheet, expanded polystyrene, saw dust were locally available materials and false ceiling panels were made up of industrial waste material. The R-I composite was cost effective (INR 900 per sq. m, Table 2) and having a dead load (less than 50 kg/m²). Assembly 2 (broken lazed tiles, saw dust, expanded polystyrene and mineral fiber board false ceiling) was having the cost INR 1250 per sq. m (Table 2) and lesser dead load (less than 30 kg/m²).

Table 2. Actual cost incurred for the R-I construction for 3.2 X 3.2 m^2 roof area

Sr No	Item	Lumsum Local Market Rate (Rs.)	Item	Lumsum Local Market Rate (Rs.)
	Assembly 1		**Assembly 2**	
1	Aluminium Sheet	2440	Broken glazed tiles	250
2	Expanded polystyrene & sawdust	360	Expanded polystyrene & sawdust	450
3	False ceiling (industrial waste)	4400	Mineral fiber board	10000
4	Mortar, Fiber Mesh+ Labor	1800	Mortar, Fiber Mesh+ Labor	1800
	Total	**9000**	**Total**	**12500**

CONCLUSION

In order to reduce the impact of heat gain inside the buildings, sustainable reflecting cum insulating assemblies was effectively applied over concrete slab. The applied

© ASCE 2014

two compositions have significantly higher thermal resistance over conventional concrete slab. The computed thermal resistance values for sustainable composite roofing assemblies have shown correlation with the experimentally recorded and analyzed temperature values. The retrofitted assemblies resulted in 6% and 19% surface temperature reduction when the thermal resistance of the roof slab is increased by 1.9 and 3.9 times respectively with the use of sustainable materials. The applied R-I materials found to be thermally efficient, lighter in weight and cost effective for energy conservation in the buildings. The experimental investigations helped to conclude that retrofitting R-I solutions over the concrete slab found to be effective in decreasing the indoor temperature. The elaborated methodology is helpful in the application of sustainable composite material assembly as per the geographic location and local climatic condition. As the retrofitting R-I assembly is lighter in weight and cost effective it can be effectively applied to the larger areas for reducing cooling load of the built environment.

ACKNOWLEDGEMENT

This work is supported by the Department of Science and Technology, New Delhi under the grant DST SERC FAST TRACK PROJECT SR/FTP/ETA-067/2009.

REFERENCES

Abramova, I., Grinberg, Y., and Zhebrunov, V. (1990). "Heat insulators based on expanded perlite for steel teeming technology." *Ogneupory*,12, 11–14.

Al-Homoud, S. (2005). "Performance characteristics and practical applications of common building thermal insulation materials." *Building and Environment*, 40 (3), 353-366.

Al-Malaha, K., and Abu-Jdayilb, B. (2007). "Clay-based heat insulator composites: Thermal and water retention properties." *Journal of Applied Clay Science,* 37 (1-2), 90-96.

Al-Sanea, A. (2002). "Thermal performance of building roof elements." *Building and Environment,* 37 (7), 665-675.

Alvarado, J., Terrell, W., and Johnson, M. (2009). "Passive cooling systems for cement-based roofs." *Building and Environment,* 44 (9), 1869-1875.

Hasegawa, T., and Konna, Y. (2001). "A study on improvement of the thermal environment in a large building with folded roof deck plate." *In: Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan*, 473–474.

Hoyano, A., Shirai, K., Otsuka, N., and Iwamura, K. (2000). "Indoor thermal control effect of rooftop lawn-planting with thin soil layer on a wooden building." *Journal of Architectural Planning and Environmental Engineering,* 527, 15-19.

Iosifides, M. (1998). *Experience, problems and suggestions for building,* In: Proceedings of the National Conference on the Implementation of Renewable Energy Sources, NTUA-RENES Network, Athens, 18–26.

IS 875: Part III. (1987). *Wind loads on buildings and structures.*

Ishihara, O., Zhang, Q., and Shimoyama K. (1996). "Experimental study on thermal characteristics and water performance of rooftop lawn." *Journal of Architectural Planning and Environmental Engineering,* 484, 17-22.

© ASCE 2014

Jungk, K., Halceband, H., Elett, K., and Kremar, W. (1997). "Porosities for the production of lightweight brick." *Tile and Brick International,* 13 (1), 7 – 12.

Korjenic, A., Petránek, V., Zach, J., and Hroudova, J. (2011). "Development and performance evaluation of natural thermal-insulation materials composed of renewable resources." *Energy and Buildings,* 43 (9), 2518-2523.

Krishan, A., Baker, N., Yannas, S., and Szokolay, S. (2007). *Climate responsive architecture: a design handbook for energy efficient buildings*. Tata McGraw-Hill Publishing Company Limited, New Delhi.

Manzan, M., and Saro, O. (2000). "Numerical analysis of heat and mass transfer in a Passive Building Component Cooled by Water Evaporation." *Energy and Building,* 34, 369–375.

Permikina, M., and Evdokimova, U. (1991). "Heat insulating refractories based on spherical corundum for the lining of high temperature furnaces." *In: Refractories-91: Technology and Applications,* All-Russia Research Workshop, VostIO, Chelyabinsk.

Raut, S., Sedmake, R., Dhunde, S., Ralegaonkar, R., and Mandavgane, S. (2012). "Reuse of recycle paper mill waste in energy absorbing light weight bricks." *International Journal of Construction & Building Materials*, 27 247-251.

Serres, S., Trombe, A., and Conilh, J. (1997). "Study of coupled energy saving systems sensitivity factor analysis." *Building and Environment,* 137–148.

Solar radiation handbook (2008). A joint project by Solar Energy Centre, MNRE & Indian Meteorological Department.

SP: 41, Part 1-4. (1987). *Handbook on Functional Requirements of Buildings (Other than Industrial Buildings),* New Delhi: Bureau of Indian Standards.

Stelmah, T. (1990). "Perlite in the production of lightweight bricks." *Tile and Brick International,* 6, 6-10.

Suvorov, A., and Skurikhin, V. (2003). "Vermiculite — a promising material for high-temperature heat insulators." *Refractories and Industrial Ceramics,* 44 (3), 44-52.

Tanabe, T., Sayama, R., and Saito, H. (2000). "Measurement of the effect of a change in slate-roofing from single to double with water spraying on lowering the ceiling surface temperature." *In: Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan*, 507–508.

Tsang, S., and Jim, Y. (2011). "Theoretical evaluation of thermal and energy performance of tropical green roofs." *Journal of Energy,* 36 (5), 3590-359.

© ASCE 2014

Waste Management to Storm Water Management: The use of recycled plastics in storm sewer production

By Daniel J. Figola, PE and John Kurdziel, PE

The idea of recycling plastics is not new. For decades various organizations have promoted the recycling of many materials, including plastic. However, despite these efforts we as a society need to dramatically increase the amount of plastics we recycle. The US EPA estimates that approximately 64 billion pounds of plastic waste is generated per year, based on 2011 data. This accounts for approximately 12% of the total municipal solid waste. If you assume an average density of plastics as 1.5 g/cm3 (93.64 pcf) this would equate to approximately 683 million cubic feet of plastic waste.

Currently the recycling rate on plastic materials is only about 8.3%. This is one of the lowest rates out of all material classes. On average municipal solid waste as a recycling rate of 34.7%, this means that plastics are falling behind the curve. With a recycling rate of 8.3% there is currently 626 million cubic feet of plastic waste that is being sent to landfills or incinerators. In order to increase the recycling rate of plastics we need to increase the demand for recycled plastic materials on a manufacturing and consumer level.

To begin the discussion on recycled plastics one must first look at the very basic classifications for a plastic, is it a thermoset or a thermoplastic. A thermoset resin is a material that cures, hardens or sets into a given shape, generally through the application of heat or curing creating an irreversible chemical reaction in which permanent connections are made between the materials molecular chains. Common thermoset materials are glues, adhesives, rubbers, and electrical insulation. A cured thermoset material will not remelt or otherwise regain the processibility it had before being cured. Curing or setting changes the material forever. While many of these materials can be recycled in a sense, it is really more of a repurposing, such as shredding old tires for use as an athletic track. However, recycling a thermoset to reprocess into a new molded material or a new product similar to its original form is not possible. The easiest way to visualize a thermoset material is to think of an egg. Once it is fried it can never return to the form of a raw egg again.

On the other hand a thermoplastic material becomes pliable and plastic when heated, but it does not cure or set. As it cools, the thermoplastic will harden in the shape of the mold, but there is no chemical curing at work. No cross-links are formed as with a thermoset material, the

© ASCE 2014

changes seen in the thermoplastic are purely physical. With the reapplication of heat it is wholly reversible.

A thermoplastic material can therefore be reprocessed (recycled) many times. The best way to visualize a thermoplastic is to think of it as water. Water can be frozen and melted repeatedly without affecting its basic properties. Common thermoplastics are polyethylene and polypropylene. Polyethylene is used in packaging, pipes, bottles, and bags; polypropylene is used in ropes, pipe, medical equipment, and carpets.

When looking at the market for product production from recycled thermoplastics there are some limitations and considerations from a cosmetic or use standpoint. Many finished products such as water bottles and product packaging are clear. Only a clear material can be recycled to produce a clear end product. While this provides a direct demand for recycled water bottles it is not a path of reuse for plastic materials that have had color added. A typical batch of recycled plastic flake will contain a rainbow of different colored material. When blended this end result is usually a material that is a dark green or black. A final product that requires a dark color or a black color is ideal. A carbon black colorant can be added to the material stream to make the final product the desired shade of black.

Gaylord box of recycled PE flake

Typically storm sewer material produced from PE resins is black in color due to the addition of carbon black as a UV protectant. This is one of many reasons why the gravity drainage storm sewer market is the ideal place to incorporate and promote the use of recycled plastics. Not only do the aesthetics of the final product create a favorable environment, but the sheer volume of opportunity make the perfect outlet for large scale diversion of material from waste streams. It is currently estimated that the storm sewer industry is a 1.6 billion dollar market.

© ASCE 2014

This represents an extremely large amount of material that can be converted over to recycled material streams.

When looking to incorporate recycled materials into a product that has structural requirements a number of items need to be considered and addressed; material availability, contaminants, materials properties, finished product quality, and finished product use/application.

When dealing with recycled plastics it is possible, in theory, to develop a product that far exceeds the performance and quality of its virgin material counterpart. However, in doing so you may limit yourself to a small portion of the available recycled material market. Not only can this lead to issues in acquiring the needed materials to support your product production, but it also misses the mark on the ultimate goal which is diverting as much material as possible from landfills. It is important to strike a balance between available material streams and realistic finished product performance. Many are inclined to set extremely high recycled product performance levels due to the perception that recycled materials have lower performance, but thermoplastics can be reprocessed with additives to enhance and increase their basic material properties.

Contaminants are another area of concern with recycled materials, especially when dealing with curb side recycling. Provisions to eliminate and remove contaminants can and should be taken in both the recycled material processing phase and the final product production phase. We will begin by discussing the ways contaminants can be addressed during recycled material processing. When recycled materials are collected from homes and businesses they are taken to a Material Recovery Facility (MRF). At this facility the materials are bulk sorted by material type and baled. In many of these facilities the recycled material will experience a base level of cleaning, typically pressure washing. While this removes some food, dirt, and liquid residue; labels, glues, and other contaminants still exist. These materials are far from being clean.

© ASCE 2014

Recycled Material Bale

The bales are then taken to a material processing facility where they are broken up into loose material. Typically this material is passed over a section of open grating where it is shaken or vibrated. The vibrating helps encourage small debris such as caps, pieces of metal, wood, etc fall through the open grating. This is the first area of contaminate removal. After this step the material is then sorted by a plastic number.

The plastic number is the number found on the bottom of a plastic bottle. These numbers classify the type of plastic used in the produce. There are a total of 7 classifications which are seen below.

SPI Resin Identification Code	1	2	3	4	5	6	7
Type of Resin Content	PET	HDPE	Vinyl	LDPE	PP	PS	OTHER

- PET – Polyethylene Terephthalate
- HDPE – High-density Polyethylene
- LDPE – Low Density Polyethylene
- PP - Polypropylene
- PS - Polystyrene
- Other – mixed Plastics

Plastic Classification Numbers

While some facilities use automated systems to sort the plastics, many use manual labor. Hand sort is often the most efficient and accurate method of sorting the material. Proper sorting of the material is the next stage of contaminant removal. Typically when new products are being produced from one plastic material, having other plastics present can present a manufacturing issue. For example if you are producing a product comprised of polystyrene, you would not want to have large quantities of HDPE present in your polystyrene material stream. In some instances the blending of plastics, such as HDPE and LDPE can provide beneficial end results. However in order to control and predict material behavior, you must first separate the materials so they can be blended in a known and desired percentage. Regardless, the plastic materials should be separated and foreign plastics in a material stream considered contaminants.

© ASCE 2014

Manual Sorting Of Plastic Materials

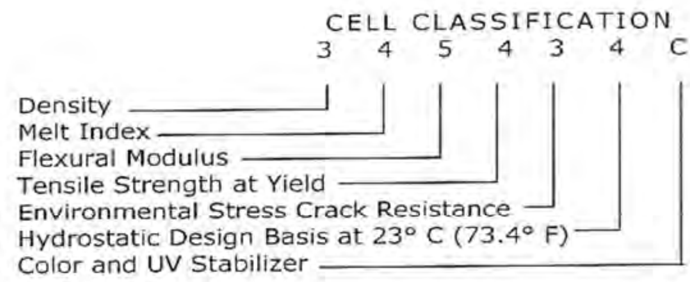
Once the plastic is sorted it is then shredded into smaller pieces. The pieces of material are washed to remove glues, labels, detergents, and other contaminants. After washing, the plastic flake then goes through a drying process to remove the water from the wash process prior to being boxed for shipping.

Box of Recycled Flake after washing and drying

Once the final materials blend has been determined the plastics can be mixed, melted and extruded into the final product. Precautions should also be taken during the manufacturing process to ensure removal of any remaining contaminants. Screens can be utilized in the production equipment. The melted plastic is pushed through a series of mesh screens. The melted plastic passes through the screens and any remaining contaminants are trapped by the screens. While this process can add cost to the manufacturing process it helps to ensure final product quality.

© ASCE 2014

When preparing to produce a new product from recycled material it is important to determine what the performance characteristics of the plastic material blend should be. Currently in the area of recycled storm sewer production there is an ASTM Specification which allows for the use of recycled materials. This specification is ASTM F2648. Within this specification there is a material requirement, often referred to as a Cell Classification. The Cell Classification is listed at 424420C. This classification is a code that describes the 7 minimum material performance requirements of the plastic materials used to produce the pipe product.



In some instances a recycled material stream may have higher performance levels that those needed for the final product. However greater performance levels may not always be desirable, for example as density increases in a plastic, its stress crack resistance may decrease. Often times multiple streams of plastics is required to obtain the desired results. Blending also allows you to use a wider range of recycled materials. You can use a recycled plastic with low performance levels by blending them with higher performing virgin or recycled material streams.

The life cycle of pipe can range from 25 to 100 years or longer, so it is a huge benefit to utilize recycled materials in pipe. The idea of taking a short-term product like a milk container and locking those materials up for a century is one of the most effective and environmentally responsible actions one can take to the betterment of not only the environment by society as a whole. This process upgrades the material from a consumer product to an infrastructure product by simply modifying and enhancing what was in the past considered a refuse product after it was used for its primary container function.

This pipe recycled process is not simple or straight forward. It requires a considerable amount of engineering design and chemical processing. Infrastructure projects must last for a minimum of 25-years, that means the plastic that is being recycled must last at least that long. All plastics are time dependent materials that can degrade over time if they do not have stabilizers and properties with inherently high long-term values. The plastics that are typically utilized for consumer products, such as containers, have reasonable very short-term values but very poor

© ASCE 2014

long-term values. In other words, if you were to place the material used in a milk container under a constant stress for over a year, it's strength would start to decrease and the material would begin to breakdown. This process would be accelerated as it is exposed to sunlight, chemicals, high or low temperatures and even the water.

The long-term thermoplastic engineering properties that are critical for pipe are tensile, modulus, ultraviolet (UV) resistance and stress crack resistance. The modulus and tensile properties determine how much load can be exerted on the pipe without it structurally failing. The stress crack resistance and UV resistance determines how long the material will perform under field environmental conditions without it cracking. A final component of these long-term property requirements is oxidation or the deterioration of the material due to simply exposure to the air. Anyone of these items can result in the failure of the pipe.

It is therefore imperative to know what type of recycled material you are dealing with prior to pipe production because a weakness in any one of these areas will result in the pipe not reaching its intended design life. As you would expect, the design requirements for agricultural drainage products are less than those for storm sewers which in turn are less than those for sanitary sewers. As the critical nature of the application increases, so do the requirements on the pipe resins and thereby the quality of the recycled materials. For this reason not all recycled materials are created equal. Some materials contain much higher long-term properties than others. To develop a product for each of these markets, it is common to blend high quality recycled materials and virgin materials with poorer quality recycled products to enhance or "sweeten" the mix. Such a complex blending process allows the production of recycled materials for any application.

The idea of recycled materials in construction use is common, especially in roadways. We see requests for recycled asphalt, recycled and rubblized concrete, and recycled content in steel items. Expanding to the use and promotion of recycled storm sewers should be an easy transition in this sector. Not only will it help improve the sustainability of our roadways, but it will provide an amazing opportunity to divert million of pounds of waste plastic away from landfills. As engineers we have taken an oath to protect the public. I believe protecting the environment goes hand in hand with protecting the public. We should strive to find new and useful ways to reuse waste materials. Although you may not be involved with product creation, you can be involved in creating a demand for recycled products once they are created.

© ASCE 2014

Performance Benchmark of Greenhouse Gas Emissions from Asphalt Pavement in the United States

Xiaoyu Liu[1], Qingbin Cui[2], and Charles Schwartz[3]

Abstract

Hot mix asphalt (HMA), used extensively in road construction, has the highest greenhouse gas (GHG) emission intensity among construction subsectors. In the absence of an authorized performance benchmark in the pavement industry, current prevailing practices of HMA form an institutional resistance to change, and emission mitigation efforts are unable to be quantified and rewarded. The objective of this paper is to develop a performance benchmark for sustainable asphalt production based on GHG emission performance. The baseline configuration is the use of conventional HMA. System boundary, functional unit, and calculation method are standardized to support the consistency of the benchmark. A sampling survey of hot mix facilities and placement projects has formed the data pool to conduct the statistics analysis. Results show that the performance benchmark is 115kgCO_2e/MT HMA. It represents an emission level that 80% of existing HMA producers are unable to reach, which reasonably avoids the occurrence of free-riders. Under the carbon trading mechanism with an assumed price of $15/MT carbon, expected benefits from producing a foam stabilized base (FSB), a less carbon-intensive asphalt material, can be $0.7/MT asphalt using CCPR process and $4.2/MT asphalt using CIR process. With the aid of a predetermined performance benchmark, rapidly evolving carbon trading markets may increase the competitive advantages of “green” production in terms of investment offset through carbon trading.

Keywords: greenhouse gas, performance benchmark, hot mix asphalt, pavement

1. Introduction

Asphalt is the most widely used pavement material in the world. In the United States, more than 92% of the 4 million kilometers (km) of paved roads and highways are surfaced with asphalt; in Europe, more than 90% of the total 5.2 million km are surfaced with asphalt. Canada has about 415,000 km of paved roads, of which about 90% are surfaced with asphalt [1]. The asphalt pavement industry is of vital importance to the economy and job creation. In 2007 alone, the United States produced over 500 million metric tons (MT) of asphalt at roughly 4,000 asphalt production sites, with an economic value of 30 billion dollars [2]. More than 300,000 workers are employed in the manufacture, transport, and placement of asphalt [3]. As existing

[1]Ph.D. student, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742. Tel: (301) 364-7988, Email: liuxy@umd.edu
[2]Assistant Professor, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742. Tel: (301) 405-8104, Email: cui@umd.edu (CORRESPONDING AUTHOR)
[3] Professor, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742. Tel: (301) 405-1962, Email: schwartz@umd.edu

© ASCE 2014

infrastructure ages and growing population requires expanded capacity, the demand for pavement materials will continue to increase. The challenge is to meet this growing demand using environmentally sustainable engineering practices. Under this initiative, the federal agency is committed to reduce energy intensity by 30% by fiscal year 2015, and reduce greenhouse gas (GHG) emissions in absolute terms by FY 2020, relative to an FY 2008 baseline.

Asphalt pavement has the highest GHG emission intensity among construction subsectors. The U.S. Environmental Protection Agency (EPA) reported that hot mix asphalt (HMA) production emitted over 300,000MT of GHG in 2010, accounting for 4.3% of the total non-combustion GHG emissions in petroleum systems [4]. Its emission intensity was 0.48MT of GHG equivalent per thousand dollar ($MTCO_2e$/k$). Value added for the asphalt pavement is 1.6 times greater than for power and communication lines, yet GHG emissions from asphalt pavement are more than five times those of power and communication lines [5]. In addition to GHG, the EPA also estimated an annual pollutant production of 25~34MT for a typical asphalt production plant; the pollutants include sulfur dioxide (SO_2), nitrogen oxide (NO_x), carbon monoxide (CO), volatile organic compounds (VOC), and volatile hazardous air pollutant (HAP) organic compounds [6].

GHG emissions have been monitored and controlled under binding environmental regulations and legislation. The U.S. Supreme Court decided, in an environmental landmark case in 2007, to grant the EPA the authority to regulate carbon emissions under the Clean Air Act [7, 8]. New facilities having large stationary emission sources, e.g., power plants and petroleum refineries, are now regulated to meet required carbon emission targets set by EPA rules and standards [9]. Those regulations set higher environmental stewardship across all industries, including the asphalt industry, to preserve the natural environment, reduce waste, and provide a cost effective material for pavement construction with equal or improved performance. Under this initiative, the asphalt industry has improved its environmental performance over the past decades. The total emissions of the asphalt industry have decreased by 97% from 1970 to 1999, while the production of asphalt pavement materials increased by 250% [10]. The industry is gradually buying into environmental incentive programs, including the GreenRoad rating system, which treats asphalt recycling as a credit in rating road environmental stewardship [11].

Recycled materials and low temperature techniques have been used in asphalt pavement to reduce GHG emissions. More than 90 million MT of reclaimed asphalt pavement (RAP) are produced every year, which accounts for approximately 80% of asphalt pavement excavated in the United States [12]. New Jersey, in particular, has doubled the use of RAP since 2001 [13]. Increasing use of RAP has significantly reduced the GHG emission during asphalt production, which has been demonstrated by the Fairfield consulting study [14]. The use of warm mix asphalt (WMA) is another emission mitigation approach that allows production at lower temperatures ranging from 212ºF to 280ºF, as compared to hot mix production temperatures in the range of 320^{o}F [15]. WMA have been broadly adopted by 40 U.S. states since it was first publicly demonstrated in 2004, and has achieved an average emission reduction of 5% [2]. The use of a foam stabilized base (FSB) blends the advantages of high RAP percentage and low mixing temperature. It is manufactured in a central plant using 100% RAP in combination with a small amount of hot bitumen blended together with 1~2% potable water. The opportunity for generating GHG reductions using FSB arises primarily from the elimination of the use of energy stocks to heat aggregates because FSB is well suited for mixing with cold and moist aggregates,

© ASCE 2014

and the elimination of the need to quarry and transport virgin aggregates through 100% recycling in the FSB production.

Despite a significant emission reduction opportunities, the GHG performance of asphalt producers is not well regulated due to a lack of standardized performance benchmarks. Pavement contractors select the use of HMA, WMA, FSB or other materials primarily based on institutional preference and the material's performance, price, and availability. Current prevailing practices regarding HMA lead to an institutional resistance to change. The objective of our study is to develop a performance benchmark for sustainable asphalt production based on GHG emission performance in pavement construction. The baseline configuration is the use of conventional HMA, which represents approximately 95% of the pavements constructed in the United States. A performance benchmark is established based on the standardized system boundary and functional unit, which allows a measurement of emission removal potentials by adopting mitigation techniques. A sampling survey of hot mix facilities and placement projects has formed the data pool to support the accuracy of the benchmark. An illustrative example is presented to show the application of performance benchmark in quantifying emission reductions by using environmentally friendly asphalt production techniques. The decision-making tool can be valuable to public agencies that are increasingly mandated to establish GHG emission standards used for attaining the low-carbon engineering practices, and asphalt producers who want to get recognition for their efforts to reduce GHG emissions.

2. Literature review

Under the general guideline of the ISO 14040 series publications, GHG reporting protocols have been developed to specify the requirements for the assessment of the life cycle emissions and serve as a reference for current estimation models/tools [16-19]. Existing pavement studies establish additional principles and techniques that address the scope, procedure, and data requirements of GHG assessment. They were intended to provide guidance for performing well-documented and transparent LCAs across all relevant GHG impacts. Primary GHG assessment tools include:

- Project Emission Estimator (PE-2 Tool) developed at the Michigan Technological University;
- Pavement Life-Cycle Tool (PaLATE) developed at the University of California, Berkeley;
- Asphalt Pavement Embodied Carbon Tool (asPECT) developed by the Transport Research Laboratory, UK;
- Pavement Life-cycle Assessment Workshop from the University of California Pavement Research Center;
- Carbon Footprint Estimation Tool developed at the University of Maryland, College Park;
- Pavement GHG Emission Estimation Framework developed at Yonsei University, Korea;
- Road Construction Emission Model developed by Sacramento Metropolitan; and
- Carbon Calculator for Construction Activities developed by the UK Environment Agency.

Given the inevitable time, data, and knowledge constraints, users of the above assessment tools have been forced to simplify the scope and use the data specific to particular locations. Most of existing estimation results can only represent the GHG performance of a specific facility or project. They vary with the tool's system boundary and functional units. As a result, there is a

© ASCE 2014

lack of agreement concerning results in the existing body of asphalt production emission estimation.

Due to the unrepeatable characteristics of the pavement activities, the existing project-based approach is insufficient to set up an explicit performance benchmark against which emission reduction by using mitigation technique can be assessed. The estimated emissions from the pavement structures are heavily influenced by the number and types of layers, the types and thicknesses of materials, the design life, the location, traffic, and other project-specific details. The challenges are the establishment of accurate emission estimation under the business as usual case, and a critical requirement for extensive data on asphalt life cycle energy usage. Early studies reported life cycle GHG emissions of conventional HMA pavements from 300 to 1500 MT per lane mile [20, 21]. The variation depends upon the mix process and proportion of reclaimed asphalt pavement in the asphalt mixture. Simply taking length as the unifying functional unit (e.g., $MTCO_2e$ per lane-mile) is not sufficient. While determining the emissions from HMA production, detailed data regarding energy consumption during material extraction and processing must be obtained to make a comparable emission calculation. A reasonable comparison should be conducted upon standardized emission boundaries with a consideration of differential climate region, pavement structure and hauling distance.

3. Methodology Framework

3.1 Baseline scenario and emission boundary

The baseline scenario applying this methodology is the production of conventional HMA. Typically more than 70% of virgin aggregates are used in HMA production. They need to be quarried, transported to the central plant, sorted into cold bins, dried by the heaters, blended with hot bitumen binders, and then fed into a mixer. The emissions associated with a series of these processes are the additional emissions compared with the materials that are produced by 100% recycled aggregates. Therefore, the primary emission reduction opportunities come from eliminating the production and processing of the virgin aggregates, and also the need to heat and dry the aggregates.

A map of the HMA life cycle is drawn in Figure 1. A Cradle-to-gate assessment principle is followed, which takes into account all life cycle stages, from raw material extraction up to the point at which it leaves the organization undertaking the assessment. The GHG content of an individual asphalt mixture is calculated as the summation of the emissions from following elements: 1) material production: the cradle-to-gate GHGs from each of the constituent materials and ancillary materials; 2) transportation: the GHGs from diesel/gasoline usage when transporting materials from factory gate to plant; 3) facility operation: GHG arising from all forms of energy involved in producing the asphalt at the mixing plant, including energy for office on site; 4) placement: GHG arising from the process of milling the existing pavement and placing the new one, associated with relevant transport activities. The boundary of the system life cycle excludes the GHG emissions associated with the production of capital goods having lifetimes longer than 1 year, and the transportation of employees to and from their normal place of work.

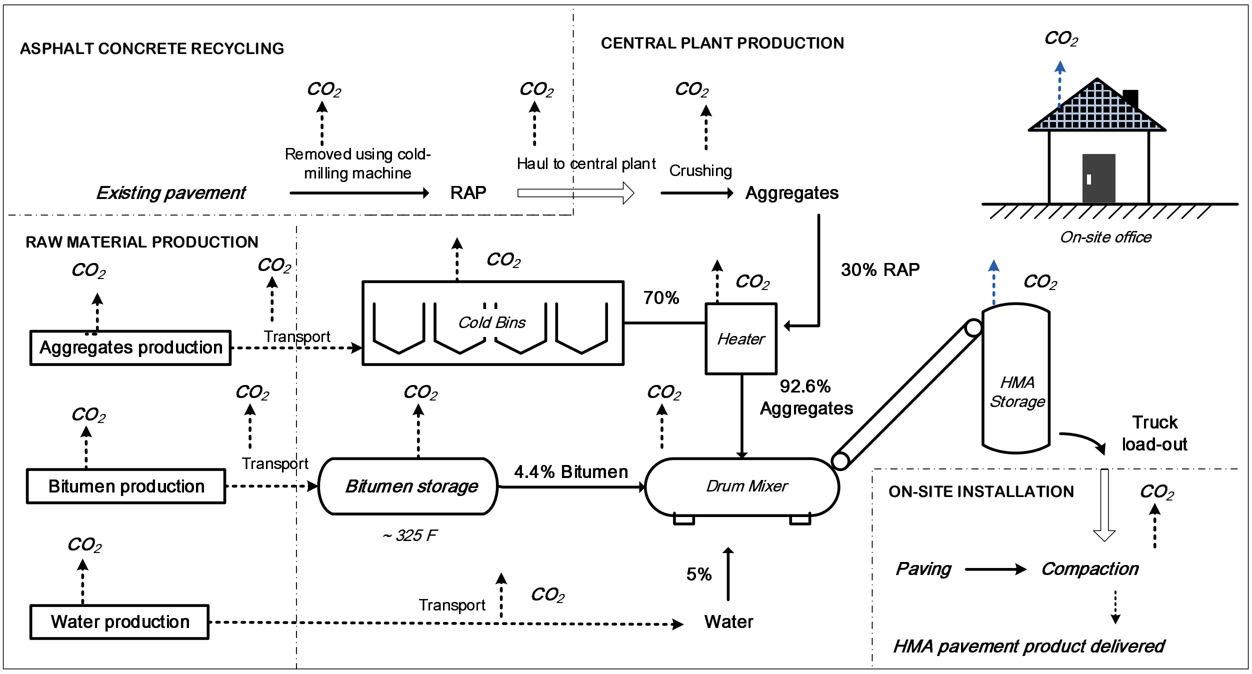


Figure 1 diagram of HMA production and placement

3.2 Calculation method and data collection

A model was created to calculate the GHG emissions associated with the production of 1MT of HMA pavement. It referred to the Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services, issued under the Publicly Available Specification [17]. Total emissions from HMA pavement are the summation of the emissions from all the life-cycle stages, including raw material production, transportation, product manufacture and installation. Global warming potentials were characterized with the IPCC 2007 methodology using a 100-year time horizon (25 and 298 for CH_4 and NO_2, respectively) [22].

The component materials of HMA include aggregates, bitumen binders, and other components. The GHG emissions from material production and transportation include 1) the embodied GHG emissions of construction materials, which are primarily due to their stoichiometric relationships based on the chemical compositions and energy consumption for the production process before transportation to destinations, and 2) GHG emissions from fuel consumption for transporting materials to production facilities [23]. The amounts of material inputs can be collected onsite at the central plant over consecutive months. Transportation distances for the shipment of input materials can be collected from the plant records. GHG emissions from raw material production and its upstream processes can be calculated using publicly available databases such as the Economic Input-Output LCA model [24] and the Inventory of Carbon and Energy [25]. The details on the emission input parameters and equations for material emissions are presented in our previous paper [26].

Primary equipment/vehicles used for placing HMA may include asphalt paving machines, backhoes, bobcat/loaders, sweeper/brooms, air compressors, rollers, trucks, etc. The GHG emissions from the equipment operations are estimated from the hours of use, the number of

© ASCE 2014

pieces on site, and equipment-specific parameters such as the emission factor, the horsepower, and the load factor. The NONROAD2008 database provides the emission factors for 25 basic categories of equipment, but it does not distinguish the difference between various engine makers within the same type of equipment [26]. To address this problem, engine emission information has been gathered from the EPA off-road engine certification database that stratified equipment types by engine maker and horsepower rating [27].

Equipment operation information should be gathered from typical pavement projects that are completed using hot mix. For each project, the operation information for trucks, which deliver the hot mix to the job site and carry the RAP from the job site to the central plant, can be obtained from truck driver reports. The truck driver reports record the time in and out from the job site for each truck, the total mileage travelled, and the gallons of diesel used by each truck. The recorded information can then be used for estimating the GHG emissions from the trucks when transporting the raw materials/products and loading/dumping the materials at both the job site and the central plant. The operation of the rest of the equipment/vehicles can be obtained from the contractor's daily report in terms of total labor hours. Total labor hours are not good measures of the effective operation time of the equipment because equipment is rarely used continuously throughout a project. To address this problem, the percentage utilization (PU) should be calculated using the effective operation time divided by the total labor hours. Different PU (the rest of time is for idling and moving) will produce different amounts of GHG emissions. According to the study by Lewis et al. [28], the emission rate of idling equipment is about one quarter of the emission rate of the operating equipment. This difference is simplified and incorporated into the emission calculation as an average activity factor (AF), which equals PU+0.25(1-PU). For example, a John Deere backhoe operates 8 hours a day with an emission factor (EF) of 87.8 kg CO_2e/hr. The PU of the backhoe in the patching project is estimated at 0.10. The actual GHG emissions from the backhoe should be [PU+0.25 (1-PU)] · EF· HR = 228.3 kgCO_2e. Emission control technology is not considered, although it is increasingly used for some categories of off-road equipment, especially equipment operated in urban areas. The formula for equipment emissions is presented in Equation 1 [29-31].

$$E_{Equipment} = \sum_i EF_i \cdot HP_i \cdot HR_i \cdot (PU_i + 0.25(1 - PU_i)) \qquad \text{Equation 1}$$

in which:

i: Equipment type that includes cold milling machine, backhoe, bobcat/loader, sweeper/broom, excavator, air compressor, paver, roller, water truck, truck, *etc*.
EF_i: Emission factor for equipment *i*, MTCO_2e/hp-hr
HP_i: Horsepower of equipment i, hp
HR_i: Total hours of on-site use of equipment i, hr
PU_i: Percentage time of utilization

4. Determination of performance benchmark

4.1 Baseline emission from material production and facility operation

The GHG emissions released from the hot mix facility and its upstream raw material production have been estimated through the survey of sixteen hot mix producers in Pennsylvania, Virginia, and Maryland. Each producer reported raw material consumption and delivery distance, and fuel use by the rotary dryer plus additional fuels used inside the gate by equipment and vehicles on a quarterly basis in 2013. GHG emission intensity is estimated using the method described in Section 4.1. A calculation example for an individual HMA facility is displayed in Table 1. The sample has a mean value of 86.1 kgCO_2e/t and a standard deviation of 15.7 kgCO_2e/t. The sample value ranges from 59.4 kgCO_2e/t to 111.9 kgCO_2e/t.

Table 1 Calculation example of a hot mix facility Operation period: 7/1/2013 to 9/30/2013

HMA output	92903.0 US ton		**Type:** Drum		
Raw Material Production					
	Quantity		Mix design	Emission factor	tCO_2e
Crushed Rock	76,180.5	US ton	82%	0.056 kgCO_2e/kg	3,839.50
Sand	7,432.2	US ton	8%	0.005 kgCO_2e/kg	33.45
Rap	4,645.2	US ton	5%	0 kgCO_2e/kg	0.00
Bitumen	4,645.2	US ton	5%	0.48 kgCO_2e/kg	2,006.70
Plant Production					
		Usage	Unit	Emission factor	tCO_2e
Plant Combustion	Fuel oil	158,614	GAL	10.18 kgCO_2e/gal	1,614.69
Equipment & Vehicles	Diesel fuel	5,336	GAL	10.21 kgCO_2e/gal	54.48
Line Power	Electricity	297,000	kWh	0.51 kgCO_2e/kWh	150.80
Raw Material Delivery					
	Distance	Round	Fuel use	Emission factor	tCO_2e
Bitumen	65mile	185.8	1 gal/mi	10.2 kgCO_2e/gal	153.00
Crushed Rock	11mile	3,047.2	1 gal/mi	10.2 kgCO_2e/gal	424.64
Sand Rock	31mile	297.3	1 gal/mi	10.2 kgCO_2e/gal	116.75
Total emissions, tCO_2e	8394.01	**Emission intensity**, kgCO_2e/MTHMA			99.39

4.2 Baseline emissions from asphalt placement

Ten projects performed in Maryland and Virginia have been surveyed to calculate benchmark emissions from HMA placement. For each project, the operation information for trucks, which deliver the hot mix to the job site and carry the RAP from the job site to the central plant, was obtained from truck driver reports. The truck driver reports recorded the time in and out from the job site for each truck, the total mileage travelled, and the gallons of diesel used by each truck. The recorded information was used for estimating the GHG emissions from the trucks when transporting the recycled materials/products and loading/dumping the materials at both the job site and the central plant. The operation of the rest of the equipment/vehicles was obtained from the contractor’s daily report in terms of total labor hours. Three out of ten projects were selected to manually assess the utilization rate of each individual piece of equipment. The percentage

© ASCE 2014

utilization (PU) was calculated using the effective operation time divided by the total labor hours. The average PU values are 0.55 for the asphalt-milling machine; 0.10 for the backhoe; 0.10 for the bobcat/loader; 0.4 for the sweeper/broom; 0.10 for the excavator; 0.33 for the paver and 0.45 for the roller. Using Equation 1, GHG emissions from ten HMA replacement projects are calculated and the results are displayed in Table 2. The sample has a mean value of 63.7kgCO_2e/MT and a standard deviation of 28.0kgCO_2e/MT. The sample value ranges from 45.0kgCO_2e/MT to 135.2kgCO_2e/MT.

Table 2 GHG emissions from HMA replacement

			Equipment hours per MT asphalt		
	EF (kg/hr)	PU	Mean	Min	Max
Milling	133.1	0.55	2.0	0.9	4.3
Backhoe	82.1	0.1	1.0	0.5	2.1
Bobcat/loader	145.7	0.1	2.3	0.7	4.3
Sweeper/Broom	108.2	0.4	3.7	0.8	7.3
Paver	128.0	0.33	2.1	0.8	3.7
Roller	46.2	0.45	4.1	0.9	8.7
Truck (onsite)	226.1	1	2.8	1.2	9.3
Truck (offsite)	10.2kg/mile	1	30.8mi/MT	17.4mi/MT	47.9mi/MT
GHG emissions, kgCO_2e/MT			**63.7**	**45.0**	**135.2**

4.3 Overall Performance Benchmark

Performance benchmark is determined based on the sum of GHG emission intensities from raw material production, hot mix facility, and placement process (the sum of results in Section 4.1 and Section 4.2). Random combination of results in Section 4.1 and Section 4.2 is used to generate 160 sampling points, which represent all the possible values of emission intensities based on the sampling population. Calculation results show that the average emission intensity (μ) of 160 sampling points is 158.2 kgCO_2e/t HMA and the standard deviation (σ) is 52.7 kgCO_2e/t HMA. According to the CDM Tool for the Demonstration and Assessment of Additionality [32], the performance benchmark is defined as an emission level that 80% of existing HMA producers are unable to reach. Assuming the sampling population follows normal distribution, as shown in Figure 3, the performance benchmark should be 115kgCO_2e/MT HMA (equals to μ- 0.84σ).

5. Application of performance benchmark

The application of performance benchmark is illustrated by an example in which the GHG emission removals by using FSB are quantified. Quantification of emissions reduction as compared to baseline scenario (the emissions from HMA here) must be made with caution: differences in system boundaries and material structural performance strongly influence the claimed reduction. It is with these cautions that we introduce the adjusted emission intensity to offer comparisons for FSB against HMA. The structural layer coefficient of FSB is 0.32. It is compared against a 19mm HMA base mix, of which Maryland State Highway Administration assigns a layer coefficient of 0.40. In this case, assuming the structural capacity is 1 for HMA, the structural capacity for FSB should be 0.8, which represents approximately 25% additional amount of FSB must be used to achieve the same performance standard as HMA. When

© ASCE 2014

factoring in this strength performance, adjusted emission intensity is expressed as the life cycle emissions from 1MT of the pavement divided by the structural capacity, and better reflects the emission reduction including the different strengths of the FSB vs. HMA materials.

Cold central plant recycling (CCPR) is one of the two principal methods for producing FSB. CCPR requires milled RAP to be transported from an existing jobsite to a central mixing plant. The unheated RAP is then blended with foamed asphalt and a small amount of Portland cement in a cold mixing process. Much of the operation data was collected onsite at a local FSB facility over five consecutive months (March 2012 to July 2012). These primary data include amounts of RAP, bitumen, water, and Portland cement over the analysis period. Transportation distances for the shipment of input materials were collected from plant records. The milling and placement procedures for a CCPR overlay are the same as for HMA. Similar to the estimation for the HMA system, the equipment operation information for CCPR was gathered from thirteen projects conducted in Maryland and Virginia.

CIR is another principal method for producing FSB. CIR uses one or more mobile recycling machine for milling, FSB production (foamed asphalt injection and mixing), and placement in a continuous operation at the pavement site. Generally, CIR uses 100% RAP generated from the existing pavement, with a treatment depth ranging from 2~6 inches. Similar to CCPR, the GHG emissions from the material in CIR come from the embodied carbon of the construction materials and the fuel consumption for transporting materials to construction sites [23]. A large portion of the operational data was collected from three projects in Virginia and California via direct measurement and interviews with the project managers. Primary data include the length, width, and depth of the replacement section, the mix design, and FSB density. Transportation distances for the shipment of input materials were collected from the records of the truck drivers. The source of emission factors for CIR is the same as that for CCPR system.

Figure 2 compares the life cycle GHG emissions from CCPR and CIR with the performance benchmark. The adjusted emission intensity of CCPR and CIR processes are 101.3 $kgCO_2e$/MT, 37.3 $kgCO_2e$/MT, approximately 12% and 67% lower than the predetermined performance benchmark. Materials production and transport, plant energy combustion, and pavement construction offer vast opportunities for emission reduction. As shown in Figure 4, the material embodied emissions of FSB (both CIR and CCPR) showed the largest emissions reduction of 43-45 $kgCO_2e$/MT. This is not surprising given that FSB typically uses 50~55% less binder and eliminates the need for virgin aggregates. The second-largest emission reduction occurs at plant energy combustion, primarily from eliminating the use of energy stocks to heat aggregates and store the produced asphalt. In the case of CIR, the emissions from plant combustion, vehicle and electricity use are totally avoided by packaging the entire production process into the on-site installation and therefore eliminating the need for the plant facilities. CCPR shares the similar plant production process and emissions as HMA production. Yet most of the HMA plants installed integrated machinery that consume natural gas (53.03$kgCO_2$/MMBtu), which releases significantly less GHG than the use of electricity (251.46$kgCO_2$/MMBtu) and diesel (75.90$kgCO_2$/MMBtu) [18]. The third emission reduction of FSB is from its construction process. CIR uses an integrated machine that combines the milling and paving processes, eliminating the need for the sweeper, bobcats/loaders, backhoes, and air compressor that account for 42% of the emission from traditional construction process on average. CCPR and HMA have similar construction-stage emission intensities due to their similar onsite processes.

© ASCE 2014

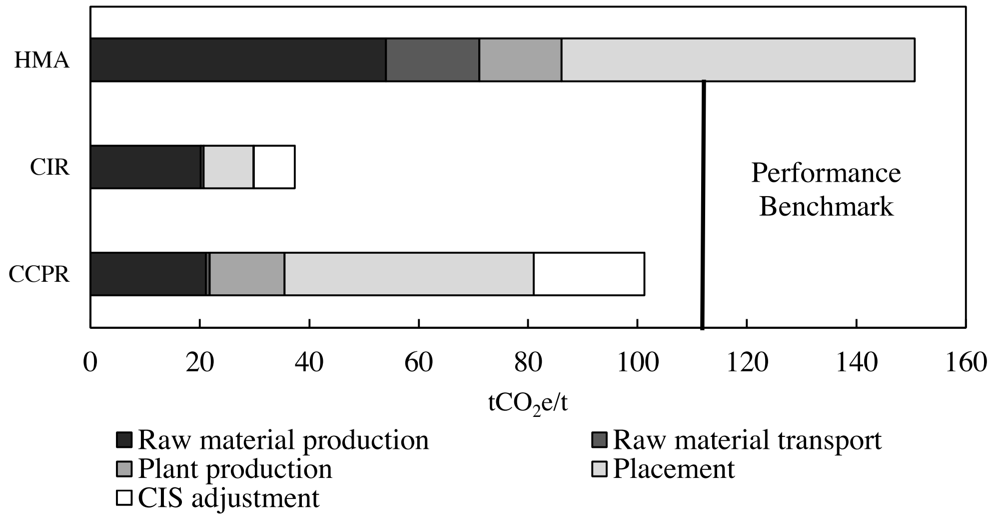


Figure 2 Comparison of GHG emissions from CIR and CCPR with performance benchmark

In light of increasingly expanded carbon trading market in the United States, a cap-and-trade scenario is framed to simulate the adoption of FSB in pavement and the investment return on emission mitigation. In the cap-and-trade scenario, cap-and-trade policy uses a predetermined performance benchmark to fix the asphalt emission intensity and applies a market mechanism to reduce GHG. If the actual amount of GHG emissions is higher than the cap in a year, the cost to cover the excess emissions for that year must be considered. Conversely, if the actual amount of GHG emissions is below the cap, the asphalt producer can then obtain revenue from selling the surplus amount of GHG reduction. The carbon price is assumed to be $15/MT carbon. Based on the above assumption, FSB producer may be eligible to claim 13.2 kgCO_2e/MT for CCPR process and 77.2 kgCO_2e/MT for CIR process. For a typical FSB producer with annual output of 1,500MT, expected benefits from reducing GHG emissions can be $1,089 for the CCPR process and $6,369 for the CIR process.

6. Conclusion

A performance benchmark has been developed to serve as a baseline emission for quantifying GHG removals by using environmentally friendly substitute asphalt materials. The baseline configuration for determining the benchmark is the production of conventional HMA. Standardized estimation boundary and calculation method have been established to measure the GHG emissions from producing and placing HMA. Sampling surveys of typical HMA facilities and placement projects form a data pool to support the determination of a conservative performance benchmark that represents the different geographic areas, pavement structures, and production techniques. An illustrative example is used to demonstrate that significant financial rewards can be granted by adopting low-carbon asphalt production techniques, with the aid of the proposed benchmark under an increasingly expanded carbon trading market. Primary findings include:

© ASCE 2014

- The performance benchmark is determined as 115kgCO_2e/MT HMA. This value represents an emission level that 80% of existing HMA producers are unable to reach and reasonably avoid the occurrence of free-riders. The boundary covers the GHG emissions from raw material production, hot mix facility and placement process.
- The performance benchmark enables FSB producer to claim a reduction of 13.2 kgCO_2e/MT for CCPR process and 77.2 kgCO_2e/MT for CIR process. Adjusted emission intensity is introduced to reflect the emission reduction including the different strengths of the FSB vs. HMA materials.
- Under a carbon trading mechanism with an assumed price of $15/MT carbon, expected benefits from producing FSB can be $0.7/MT asphalt using the CCPR process and $4.2/MT asphalt using the CIR process. Rapidly evolving carbon trading markets may increase the competitive advantages of a "green" producer in terms of investment offset through carbon trading.

References

[1] M. Mangum, Asphalt Paving Sector Presentation, Health Effects of Occupational Exposure to Emissions from Asphalt/Bitumen Symposium Dresden, Germany, 2006.

[2] NAPA, Black and green sustainable asphalt, now and tomorrow, National Asphalt Pavement Association (NAPA), Special Report, 2009.

[3] NAPA, Asphalt Pavement Overview, available online at: http://www.asphaltpavement.org/index.php?option=com_content&view=article&id=14&Itemid=33, 2013.

[4] EPA, Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. U.S. Environmental Protection Agency (EPA), Washington D.C., 2013.

[5] P. Truitt, Potential for Reducing Greenhouse Gas Emissions in the Construction Sector, Environmental Protection Agency (EPA), United States, 2009.

[6] EPA, Hot mix asphalt plants emission assessment report, EPA 454/R-00-019, Office of Air and Radiation, United States Environmental Protection Agency (EPA), 2009.

[7] U.S. Supreme Court, 549 U. S. 497, Massachusetts v. Environmental Protection Agency, Opinion of the Court, Supreme Court of the United States, Washington D.C., 2007.

[8] U.S. Congress, Clean Air Act, Title 42-the public health and welfare, U.S. Government Printing Office, ed., United States Code, 5828, 2008.

[9] R. Meltz, Federal Agency Actions Following the Supreme Court's Climate Change Decision in Massachusetts v. EPA: A Chronology, Congressional Research Service (CRS) report for congress, R41103, 2012.

[10] J. Chehovits, L. Galehouse, Energy usage and greenhouse gas emissions of pavement preservation processes for asphalt concrete pavements, Proc., Compendium of Papers from the First International Conference on Pavement Preservation, 2010, pp27-41.

[11] J. Anderson, C. Weiland, S. Muench, Abridged Manual for Green roads, University of Washington, Seattle, WA, 2011.

[12] FHWA, A Study of the Use of Recycled Paving Materials: A Report to Congress, FHWA-RD-93-417, Federal Highway Administration (FHWA), Washington, D.C., 1993.

[13] A. Copeland, Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice, FHWA-HRT-11-021, Turner-Fairbank Highway Research Center, Federal Highway Administration, McLean, VA, 2011.

© ASCE 2014

[14] Fairfield, Australia's Future Infrastructure Requirements, Infrastructure Australia Discussion Paper 1, Fairfield City, 2008.
[15] B. Prowell, G. Hurley, Warm-Mix Asphalt: Best Practices. Quality Improvement Series 125, National Asphalt Pavement Association (NAPA), Lanham, MD, 2007.
[16] WRI, the Greenhouse Gas Protocol: The GHG Protocol for Project Accounting, World Resource Institute (WRI), United States, 2005.
[17] PAS, Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services, Public Available Specification (PAS) 2050, United States, 2011.
[18] The Climate Registry, General Reporting Protocol for the Voluntary Reporting Program, United States, 2008.
[19] ENCORD, Construction CO_2 Measurement Protocol. European Network of Construction Companies for Research and Development (ENCORD), France, 2010.
[20] M. Chappat, J. Bilal, the Environmental Road of the Future: Life Cycle Analysis. Colas SA, Paris, 2003.
[21] H.J. Santero, A. Horvath, Global warming potential of pavements. Environmental Research Letters 4, 2009.
[22] IPCC, Climate Change 2007: Synthesis Report, R. K. Pachauri, and A. Reisinger, eds., International Panel on Climate Change (IPCC), Geneva, Switzerland, 2007.
[23] H. Yan, Q. Shen, L.C. Fan, Y. Wang, L. Zhang, L, Greenhouse gas emissions in building construction: A case study of One Peking in Hong Kong, Build. & Environ., 45(2010) 949-955.
[24] CMUGDI, Economic Input-Output Life Cycle Assessment (EIO-LCA), US 1997 Industry Benchmark model, Carnegie Mellon University Green Design Institute (CMUGDI), 2008.
[25] G. Hammond, C. Jones, Embodied carbon: The Inventory of Carbon Energy (ICE), Building Services Research and Information Association (BSRIA), Berkshire, UK, 2011.
[26] X. Liu, Q. Cui, C. Schwartz. Greenhouse gas emissions of alternative pavement designs: Framework development and illustrative application, J. Environ. Manage. 132 (2014) 313-322.
[27] EPA, Engine Certification Data for Heavy Truck, Buses, and Engines, available online at: http://www.epa.gov/oms/certdata.htm#largeng, 2012.
[28] P. Lewis, W. Rasdorf, H.C. Frey, S.H. Pang, K. Kim, Requirements and incentives for reducing construction vehicle emissions and comparison of nonroad diesel engine emissions data sources, J. Constr. Eng. M., ASCE, 135(2009) 341-351.
[29] IPCC, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, National Greenhouse Gas Inventories Programme, Intergovernmental Panel on Climate Change (IPCC), Kanagawa, Japan, 2006.
[30] EPA, Exhaust Emission Factors for Nonroad Engine Modeling - Spark-Ignition, NR-010f, U.S. Environmental Protection Agency (EPA), Washington D.C., 2010.
[31] EPA, Motor Vehicle Emission Simulator (MOVES) 2010, EPA-420-B-09-041, U.S. Environmental Protection Agency (EPA), Washington D.C., 2009.
[32] Board, CDM Executive, Tool for the demonstration and assessment of additionality, EB16 Annex 1, 2008.

© ASCE 2014

Envision Case Study: Seaport Dolphin Berth Improvements

Evan Sheesley PE, ENV SP[1]; Brandon Whitaker[2]; Mike Wray SE, LEED AP[3], John Klekotka, SE[4]

[1] Senior Engineer, BergerABAM: 33301 Ninth Ave W., Suite 300, Federal Way, WA 98003; PH (206) 431-2300; email evan.sheesley@abam.com
[2] Environmental and Safety Specialist, Port of Everett: 1205 Craftsman Way, Suite 200, Everett, WA 98201; PH (425) 388-0613; bwhitaker@portofeverett.com
[3] Senior Project Manager, BergerABAM: 33301 Ninth Ave W., Suite 300, Federal Way, WA 98003; PH (206) 431-2300; email mike.wray@abam.com
[4] Chief of Engineering & Planning, Port of Everett: 1205 Craftsman Way, Suite 200, Everett, WA 98201; PH (425) 388-0715; johnk@portofeverett.com

ABSTRACT

The sustainable performance of a typical small marine capital improvement project was measured using the Envision™ 2.0 Guidance Manual and rating system during the fall of 2012. The Port of Everett used Envision to gauge the effectiveness of its sustainability programs, community outreach, and commitments to environmental stewardship. Through this project, the Port has a new roll on/roll off (RO/RO) facility that increases operational capacity for supporting the international construction and manufacturing industries. Using a minimal impact design strategy of integrating with an existing marine facility, construction costs and environmental impacts were reduced. The strategy included installing new—and repairing existing—mooring structures, as well as upgrading the existing fender system and removing creosote-treated timber piles. The study shows how parts of the project relate to each Envision category and how points were achieved. With this study, the project team was able to determine the compatibility and functionality of Envision with seaport infrastructure projects.

Involved in multiple sustainability programs, the Port welcomed the chance to continually improve their performance across different applications using Envision, such as in capital improvement projects. Opportunities for the Port to improve its sustainability planning and design practices are outlined in the report. Although this project was evaluated at the end of the 100 percent design phase, the Port came away with multiple examples that will improve their sustainability performance on future projects by using Envision as a guideline. Those include, but are not limited to: performing a life cycle analysis, setting sustainability goals in the project design phase, and further developing a sustainable procurement policy for contractors and vendors.

INTRODUCTION

The Port of Everett, located in Washington State, is an economic enterprise for the cities of Everett, Mukilteo, and the broader region. The Port decided to pursue emerging cargo opportunities by increasing its operational capacity through RO/RO operations. As part of embracing the principles of sustainability, the Port sought to

© ASCE 2014

measure the level of sustainability achieved by a typical Port project using the Envision rating system. The goal was to identify ways to enhance the level of sustainability involved in Port planning, development, and operations.

Many principles of sustainability are already woven into the Port's organization and activities. The Port is advancing environmental initiatives to improve air and water quality in the Puget Sound. As an active participant in the Puget Sound Maritime Air Forum, a collaboration of maritime organizations, regional air agencies, and other groups, the Port voluntarily quantifies its air emissions and develops strategies to reduce the impacts of the air pollution they generate. Some of these strategies include switching to electric gantry cranes, purchasing hybrid vehicles, and switching to low-sulfur emitting diesel fuel. The Port also employs low impact development strategies to collect and treat stormwater.

Along with its progressive policy of environmental stewardship, the Port has tracked sustainability programs since 2008 and publishes a report on the topic every three years. The Port also engages the community through a variety of outreach methods, including project outreach, publications, digital media, its open commission meeting policy, and by providing public access to the waterfront. This commitment to public engagement is returned through efforts by EarthCorps, a non-profit group that mobilizes and manages citizen volunteers. These volunteers restore areas of invasive plant species by replacing the invasive plants with mulch and plant native vegetation in their place. This work is conducted at Jetty Island (the Port's man-made habitat through beneficial placement of dredge sediment) and Union Slough, a salt-marsh restoration site.

Additionally, the Port is responsible for supporting more than 35,000 jobs (direct, induced, and indirect) and $4.2 billion in revenue in 2012. The Port consistently produces clean financial audits and received an excellent investment grade from Moody's.

BACKGROUND

The goal of the dolphin berth improvement project was to increase operational capacity to support the international construction and manufacturing industries. The project accomplished this goal by integrating the new operations with an existing facility at the Port's South Terminal. In order to berth the larger seagoing, 860-foot long, RO/RO vessels, which displace a maximum of approximately 67,000 metric tons, the facility also required upgrades to its supporting structures. Originally designed as a log-handling facility, the dolphin berth (located at the Port's South Terminal) could accommodate vessels up to 600 feet long with a maximum loaded displacement of approximately 44,000 long tons. The estimated construction cost was $1.2 million and included these four major elements; also shown in Figures 1 and 2.

- Construct one new berthing dolphin
- Repair and upgrade an existing collision-damaged dolphin
- Removal of creosote-treated piles
- Upgrade the fender system elements on all dolphin berth structures

© ASCE 2014

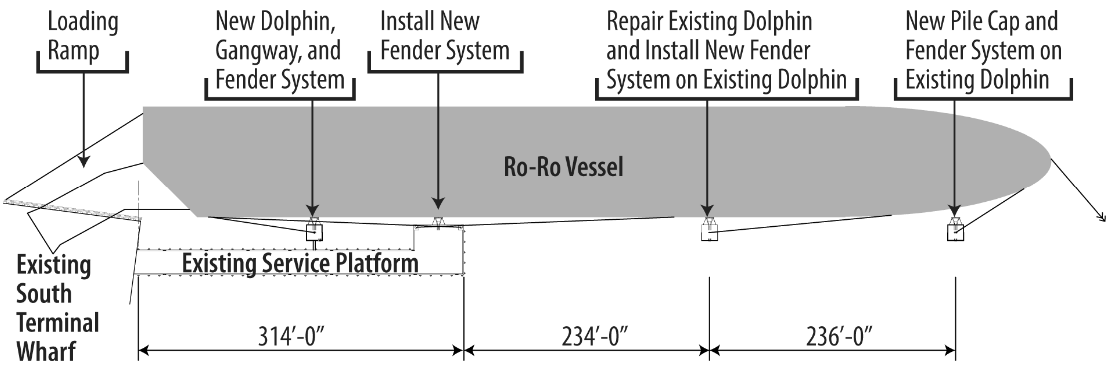


Figure 1. Site Layout

Instead of building a new wharf structure and facility, the Port looked for synergistic opportunities to integrate existing facilities and took a minimal impact approach to achieve its goals. The dolphin berth at South Terminal was targeted for the upgrade because it is located in water depths sufficient for the new operations without the need for dredging, thereby lessening the project impacts on the ecosystem. Existing collision-damaged mooring dolphins were repaired and upgraded. The existing structure was constructed well above the 100-year floodplain and anticipated 100-year sea-level rise elevation for the region, which will allow it to operate well into the future without restrictions due to climate change.

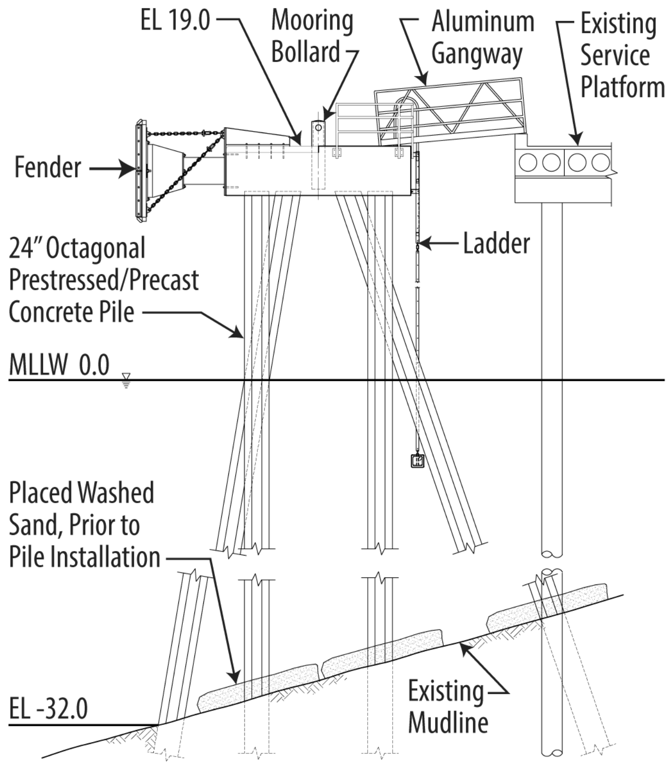


Figure 2. Dolphin Elevation

Concrete elements were chosen because, when compared to galvanized steel piles, they have a longer maintenance-free service life with lesser impacts to aquatic life. Furthermore, design synergies were implemented through the use of cementitious material. Specifically, it included replacing 25 percent of the cement in concrete with one of two industrial process byproducts, either ground blast furnace slag or fly ash, which reduces corrosion of the steel reinforcing bars and reduces heat-island effects.

Envision was used to evaluate the project at the 100 percent design phase. As a part of that evaluation, the specifications were modified to require the contractor to track its recycled content usage and locally sourced material usage (Envision credits RA 1.3 and RA 1.4). The specifications also stated that the contractor was to attain the minimum required levels for Envision credits related to these items.

RESULTS AND DISCUSSION

This section reports the results of the analysis using Envision to determine strengths and weaknesses of the project in terms of sustainability. The Envision rating tool contains five categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk. Each category is divided into subcategories to address the project's pathway and performance contributions: stakeholder engagement, cultural awareness, business sustainability, and environmental stewardship.

Pathway contribution is defined in the Envision Guidance Manual as considering "how the project aligns with overall community needs and enhances quality of life." The goals being to integrate the project with existing infrastructure, work with the community to meet their needs, and promote responsible development. This is an important part of the rating system as infrastructure projects will have impacts (positive and negative) on the host and surrounding communities for generations. Making sure the scope of the project addresses the areas outlined above to the best of its abilities will help reduce negative impacts.

Performance contribution is the efficiency with which the project accomplishes its goals by minimizing it impacts to the environment, improving the economy, and improving the host community. The effectiveness of the project to improve sustainable performance and meet all of the project's intended goals are measured through various parameters, including resource and energy conservation.

Quality of Life. The project achieved 18.7 percent of the total applicable points for Quality of Life. Nine of the 13 credits were applicable. By subcategory, the project scored 23.3 percent in Community, 10.0 percent in Wellbeing, and 21.4 percent of the applicable subcategory points in Purpose (see Figure 3).

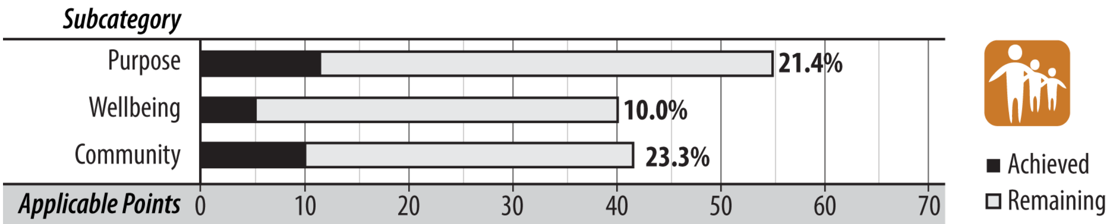


Figure 3. Results for Quality of Life Category

The Port, which consistently and constantly engages its community, informed the community about this project through the Port website, semi-annual neighborhood meetings, project permit processes, and in public meetings of the Port

© ASCE 2014

Commission. Due to the nature and small size this project, additional and more active methods of community outreach as referenced earlier were not warranted.

The Port's 2 percent policy represented the highest level of achievement, superior, which came from credit QL3.3 – Enhance Public Space. Since 1988, 2 percent of every engineer's estimate of Port capital improvement projects in the shoreline zone has been allocated to waterfront improvement projects and programs. So far, this policy has accounted for almost $4 million in enhancements to public access and public space—31 percent of the Port's public access funding. This work also helps create jobs and supports the local work force.

An enhanced or improved rating was achieved in all other credits except for QL2.2 – Minimize Noise and Vibration and QL2.6 – Improved Site Accessibility, Safety, and Way Finding, where no added value was given because the scope of the project does not address these issues beyond meeting local regulations.

Although the Port has been a good steward of the community and currently meets local noise ordinance requirements, Envision awards points for efforts that go beyond regulations. Additional points could be achieved by conducting noise and vibration studies in the adjacent neighborhoods and implement higher levels of mitigation to improve community livability beyond regulatory requirements.

Leadership. The dolphin berth improvement project achieved 18.4 percent of the applicable points for Leadership. The Leadership category is broken down into three subcategories: 18.2 percent of the planning, 18.8 percent of the management, and 18.3 percent of the collaboration subcategory points were achieved (see Figure 4). Two credits in this category, LD2.1 – Pursue By-Product Synergy Options and LD3.2 – Address Conflicting Regulations and Policies, did not apply. Large portions of the materials specified (i.e., concrete and steel) cannot be made with by-products available in the area, and there were no conflicting regulations with the project. Recycled concrete was considered for use as a portion of the concrete aggregate; however, the material available in the area is not of a structural grade and is in low supply due to high demand for local roadway projects.

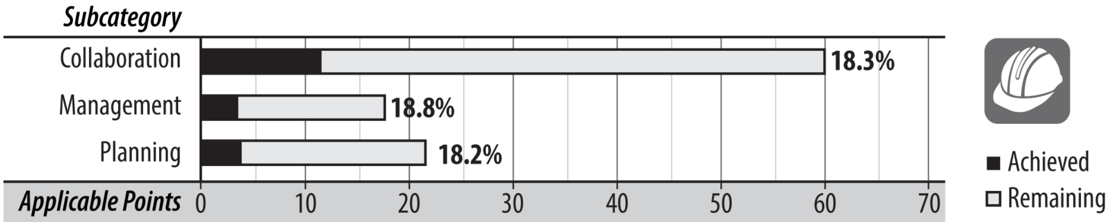


Figure 4. Results for Leadership Category

The highest level of achievement, enhanced, came from credits LD1.1 – Provide Effective Leadership and Management, LD1.4 – Provide for Stakeholder Involvement, LD2.2 – Enhance Infrastructure Integration, and LD3.3 – Extend Useful Life. An improved rating was achieved in all other credits.

The Port has publicly committed itself to sustainability. These commitments are seen in the Port environmental management system, wide-ranging community

© ASCE 2014

outreach programs, and their longstanding Moody's excellent bond rating. The Port tracks performance across all areas of sustainability yearly and reports the results triennially. The Port conserved resources for the dolphin berth improvement project by integrating it with an existing facility, which also increases operational efficiency (e.g., lower maintenance). Although the project is included in the Port's monitoring and maintenance plan, items specific to the facility for long-term monitoring were not planned.

Resource Allocation. The dolphin berth improvement project achieved 18.1 percent of the applicable points for Resource Allocation. Two credits in this category are optional (RA1.5 – Divert Waste from Landfills and RA2.2 – Use Renewable Energy), and credit RA1.5 does not apply because the operation of the project will not generate a significant waste stream and, with the exception of repairs due to damage, the constructed works are designed to be fairly maintenance-free for their design life. This category is broken down into three subcategories. Although 44.9 percent of the applicable points were achieved in Materials, no points were achieved in the Water and Energy subcategories (see Figure 5).

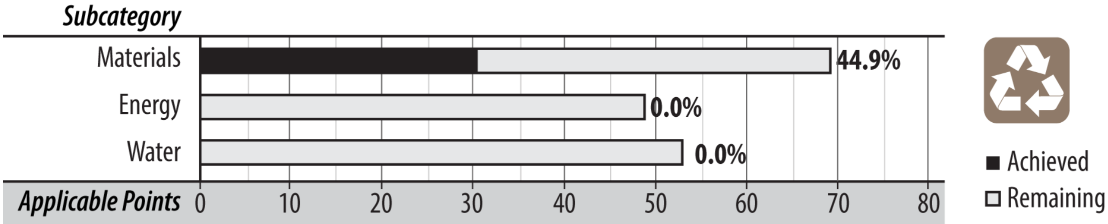


Figure 5. Results for Resource Allocation Category

The highest level of achievement, conserving, came from three credits: RA1.3 – Use Recycled Material, RA1.4 – Use Regional Material, and RA1.6 – Reduce Excavated Material Taken Off-Site. The project is reusing much of an existing wharf originally used as a breakbulk facility, and this reuse contributes significantly to the recycled and regional material content. The project team specified a minimum of 5 percent recycled materials and 30 percent locally sourced materials for new components. The project also avoids excavation, because it is reusing an existing structure.

An improved rating may be achieved in credit RA1.7 – Provide for Deconstruction and Recycling, because most construction uses recyclable material (i.e., timber, steel, rubber, and reinforced concrete). Explicit plans for deconstructing the structure were not created.

The remaining applicable credits did not earn points. These credits require the use of a life cycle analysis (LCA), creating a sustainable procurement program, reducing energy and water consumption, using renewable energy, and creating long-term commissioning plans for the facility.

Material synergies were envisioned by requiring the use of fly ash and slag in concrete mixes. The benefits of these materials are increased durability of reinforced concrete, an increase in the content of recycled material, and increasing reinforced

© ASCE 2014

concrete's Solar Reflexivity Index (SRI). The substitution of these post-industrial by-products improves concrete's durability in the marine environment because the particles of slag and fly ash are smaller than cement and decrease porosity. These substances extend service life because they act as interlocking agents to increase permeability, in turn preventing seawater from reaching the reinforcing steel and, thus, reducing corrosion. Potential increases in temperature at the surface of the platform are also mitigated because slag and fly ash are lighter in color than concrete and reflect light and heat better.

Natural World. The dolphin berth improvement project achieved nearly 41 percent of the applicable points for Natural World. Five credits in this category did not apply (NW1.2-Preserve Wetlands and Surface Water, NW1.3-Preserve Prime Farmland, NW1.4-Avoid Adverse Geology, NW1.6 Avoid Unsuitable Development on Steep Slopes, NW2.2-Reduce Pesticides and Fertilizer Impacts, and NW3.2 Control Invasive Species). These credits did not apply because the project is not near a state designated wetland or designated shoreline, was not previously landscaped, nor was it located on prime farmland or steep slopes. Natural World is broken down into three subcategories; of the applicable points, the project could achieve 48.6 percent in Biodiversity, 20.5 percent in Land and Water, and 50.0 percent in Siting (see Figure 6).

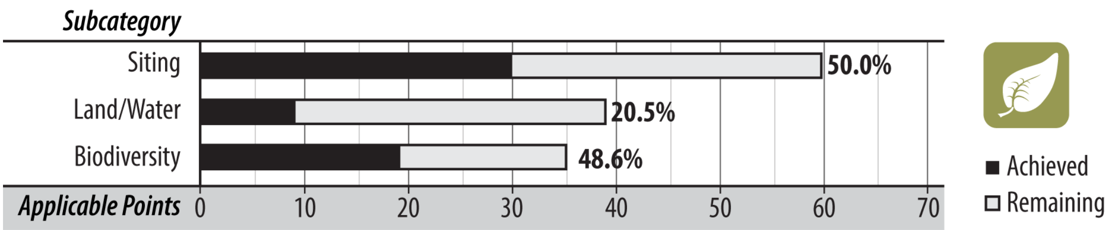


Figure 6. Results for Natural World Category

The highest level of achievement, conserved, came from credits NW1.7 – Preserve Greenfields and NW3.4 – Maintain Wetland and Surface Water Functions. The project was developed on a previously developed site (greyfield); therefore, many of the requirements in these credits are met. By minimal development on a greyfield, the existing ecosystems were maintained.

All remaining applicable credits received levels of achievement ranging from improved to superior. These points are credited for building on a previously developed site and for the Port's bioswale, a low impact development system that captures and treats 100 percent of the site's stormwater runoff. The Port was also required to avoid development on prime habitat through the Washington State Environmental Policy Act (SEPA), thereby meeting some of the criteria for this category.

Climate and Risk. The applicable points achieved for the Climate and Risk category was 36.1 percent. All credits in the category apply to the project. The category has two subcategories; of these, 53.7 percent of Resilience may be achieved, but none of the credits for Emissions were addressed directly, primarily because the Port does not meet California emissions standards nor was a life cycle assessment (LCA) performed (see Figure 7).

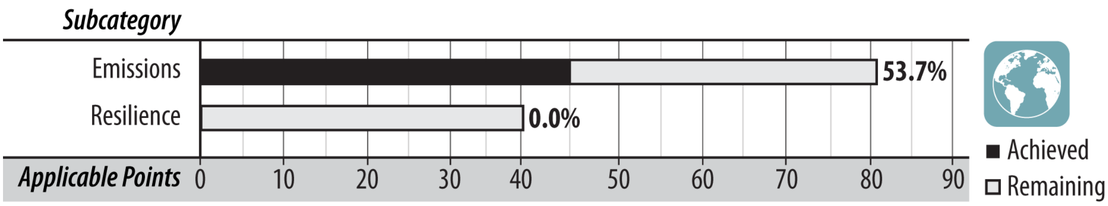


Figure 7. Results for Climate and Risk Category

As a member of the Puget Sound Maritime Air Forum (PSMAF), the Port has successfully implemented initiatives to reduce air emissions. The PSMAF is a voluntary association of maritime organizations, air agencies, and environmental and public health agencies. The purpose of the forum is to quantify and reduce air emissions from maritime activities. This includes all levels of transportation of goods and passengers, as well as operations. The Port's specific response to the reduction of air emissions includes using ultra-low sulfur, diesel-powered fleet vehicles, as well as electric and hybrid vehicles.

Results from the 2011 Puget Sound Air Emissions Inventory showed the Port has reduced emission levels based on a per 10,000 metric tons of cargo, in numerous parameters, since 2005. While the Port meets national air emission standards, Envision awards points to infrastructure projects that go beyond the benchmarks.

Envision Score. The dolphin berth improvement project could achieve approximately 26 percent (174 of 664) of the total applicable points in Envision. Points achieved in each Envision category are shown in Figure 8. Natural World scored the highest number of points (55) and the highest percentage of applicable points (41 percent), while Resource Allocation attained the lowest percentage of points at 18.1 percent. The sustainable performance of the dolphin berth improvement project would achieve the bronze level of recognition as rated with Envision. The minimum requirement to attain recognition by Institute of Sustainable Infrastructure is to achieve 20 percent of the total applicable points.

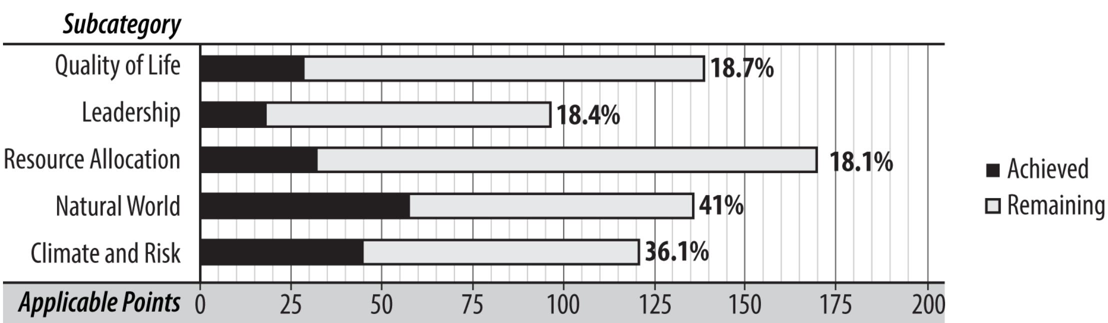


Figure 8. Results by Category

© ASCE 2014

CONCLUSION

For being a small and relatively standard capital improvement project for the Port, the dolphin berth improvement project scored well according to the Envision rating tool. This can be attributed to the Port's commitments to improving the sustainable performance of its capital improvement projects and operations. Although a Bronze was attained, several small steps can be taken on future projects to ensure better sustainable performance and thus higher Envision ratings.

Opportunities to improve sustainability should be addressed early on in a project. In this instance, Envision was used retroactively at the 100 percent design phase, meaning there were not many opportunities to improve the project's score. However, the project team did take the opportunity to increase the project's sustainability and Envision score by specifying a minimum percentage of recycled material and regional material in the construction documents. Additional points could also be achieved by conducting a life cycle analysis (LCA). Although it would not have a direct benefit to this project, it would provide an opportunity for the Port to learn how LCA can be applied on future projects during the concept design phase and its ongoing operations.

As a seaport, development in a body of water is inherent. Envision could look to provide some clarity in this category to address Port business. Credit should be given for understanding the surrounding ecosystem and developing responsible improvement strategies, not just for avoiding development in a body of water.

Although dredging was not part of the project, the Port also looks for by-product synergies through its dredge operations. Instead of deep water disposal as a first choice for dredge materials, the Port first uses them to expand wildlife habitat at Jetty Island, then finds locations within the lower Snohomish River corridor that may have a beneficial use for the material, with the remainder dumped at an approved offshore dump site. The Port has received recognition for this program, which is viewed as a model synergy for other port authorities.

RECOMMENDATIONS FOR ACHIEVING HIGHER LEVELS OF SUSTAINABILITY

A list of recommended strategies, as outlined in Envision, is provided to improve Port sustainability with respect to infrastructure planning and design. These strategies would address higher Envision levels of achievement, and increased recognition for the Port as a leader in sustainability. The strategies range from minimal to considerable efforts based on perceived time and cost associated with the action.

1. Set sustainability goals at the concept stage of capital improvement projects as well as for master planning. This early recognition of Port goals will bring sustainability to the forefront for all team members to track. It also provides a way for sustainable performance to be tracked through the design process. Goals should be in terms of the triple bottom line (i.e., economy, environment, community). A project lead should be assigned to coordinate the plan and document progress.

2. Improve adaptability for short-term and long-term hazards and climate change, including risk management. Building codes generally set minimum standards

© ASCE 2014

intended for occupant safety and to prevent collapse for the maximum considered event (storm, earthquake, etc.). Designing to larger, more frequent events or to higher levels of performance after an occurrence could be investigated. A life cycle cost analysis can show the costs associated with repairing a structure (including operational downtime) for various design strategies (ranging from building to code standard to higher design levels) over the life of a project. In short, investing more money at the beginning of a project could save money over the life of a project.

3. Include LCA at the concept phase of a project and assess strategies to reduce a project's energy consumption (embodied energy) and air emissions. An LCA is required on many of the credits within Envision. This tool is used to calculate the energy consumed through the entire life cycle of a project. A thorough analysis requires creating an inventory of all the material used, machinery operated, and grid energy sources. An LCA can also be used to determine the total amount of CO2 generated over the life of a project. Because concrete and steel make up large portions of the materials on Port infrastructure projects, the embodied energy of these products should be inventoried. Ships idling at the facility, yard equipment, and lighting make up most of the operating energy consumption.

4. Make a commitment to meet California Air Quality Standards. While the Port meets national air emission standards and has shown documented reductions in air emissions across normalized metrics, Envision awards points to infrastructure projects that go beyond regulatory benchmarks.

5. Use results from regional climate impact and risk assessments to develop port-wide strategies for project development and infrastructure improvement. Long term changes in sea-level and increases in storm intensity and frequency should be investigated on all projects. This will ensure that the facility will remain operational long into the future and require less downtime.

6. Institute sustainable procurement practices for suppliers of construction materials and during operations. This strategy will show that the Port is a leader in sustainable development by requiring companies it contracts with to uphold the same sustainable standards.

7. Incorporate long-term systems commissioning and monitoring of energy and water systems through revisions to inspection and maintenance programs. Periodic inspections of facilities could include commissioning of mechanical and electrical systems. The inspection could also include a report on how the facility is performing versus the design intent. For example, the assessment could include efficiency of operations, frequency and magnitude of repairs, energy use, and water use. Sub-meters on energy and water systems could also be installed. These actions would provide more accurate reporting on where energy is used and provide more information on performance, thereby allowing more informed decisions for correction.

8. Support cold ironing to reduce energy use. Collaborate with tenants to retrofit ships with cold ironing technology or other strategies to reduce fuel consumption while ships are moored at the Port.

© ASCE 2014

REFERENCES

Carl D. Martland. (2012). *Toward More Sustainable Infrastructure: Project Evaluation for Planners and Engineers*.

American Association of Port Authorities. (2011). *Survey, North American Container Traffic Port Ranking by TEUs*.

American Society of Civil Engineers. (2010). *Sustainability Guidelines for the Structural Engineer*.

City of Everett. (July 2011). *Hazard Inventory and Vulnerability Analysis*

Institute for Sustainable Infrastructure. (2012). *Envision Guidance Manual, Version 2.0*.

Martin Report (2012). *Port of Everett Economic Impacts*.

Port of Everett. (2008). *Community Survey*.

Port of Everett. (December 2010). *Port of Everett Sustainability Report*.

Puget Sound Maritime Air Forum. (2011). *Puget Sound Maritime Air Emissions Inventory*.

World Wildlife Fund. 2006. *Living Planet Report*.

© ASCE 2014

Sustainable Performance Evaluation of a Remediated Oil Field Using Envision™

Evan Sheesley PE, ENV SP[1]; Douglas Sereno, PE, EVN SP[2];
Mike Wray SE, LEED AP[3]

[1] Senior Engineer, BergerABAM: 33301 Ninth Ave W., Federal Way, WA 98003; PH (206) 431-2300; email evan.sheesley@abam.com
[2] Director of Program Management, Port of Long Beach: 4801 Airport Plaza, Long Beach, CA 90815; PH (562) 283-7354; doug.sereno@polb.com
[3] Senior Project Manager, BergerABAM: 33301 Ninth Ave W., Federal Way, WA 98003; PH (206) 431-2300; email mike.wray@abam.com

ABSTRACT

This paper summarizes a study piloted by the Port of Long Beach (Port) that investigated the Envision™ 2.0 rating system to understand how it applies to port infrastructure projects. The study evaluated the sustainable performance of a past project, completed in 2009, in which an active oil field facility underwent site remediation before Envision became available. After review of all pertinent and available project documentation, a team of Envision Sustainability Professionals rated the project in accordance with the Envision 2.0 guidance manual. The project was evaluated in two ways: the first evaluated the as-built condition, and the second was a hypothetical evaluation that assumed the project team was able to use Envision at the planning stages of the project. Several simple yet high-impact actions were identified that could have improved the project's sustainable performance as indicated by the Envision rating. The Port used the study to evaluate available rating systems, including the Port's own sustainable infrastructure guidelines, to objectively support and demonstrate commitment to sustainable development and operations. Guided by its Green Port Policy that showcases sustainability as one of five guiding principles, the Port's Bureau of Engineering is incorporating principles of sustainable development into its routine project delivery procedures. An appropriate rating system can demonstrate and provide an objective measure of progress against this stated goal. Lessons learned are provided to help the project manager develop more sustainable projects using the Envision guidance manual.

INTRODUCTION

Evaluation Goals. Envision was used as rating tool to evaluate the sustainable performance of the Pier A West brownfield remediation project at the Port. The study was designed to provide insight on how Envision relates to seaport infrastructure projects and how it might be used to implement and track sustainability on future projects. The Interim Source Removal Action Project for Pier A West, Area 2 site was completed in 2009, prior to the development of Envision. Because the project was not developed with Envision in mind, the evaluation was limited to the available project information. Therefore, the evaluation provided a benchmark of the Port's infrastructure development process prior to incorporating Envision guidelines.

© ASCE 2014

Green Port Policy. Adopted in 2005, the Green Port Policy established guiding principles for the Port of Long Beach to improve the natural and built environment that it operates in. The principles promote sustainability, highlight the need to engage and educate the community, and hold paramount the Port's desire to be a leader in environmental stewardship and its duty to protect the community from any harmful effects from its operations.

The Green Port Policy includes six program elements (Wildlife, Air, Water, Soils and Sediment, Community Engagement, and Sustainability) and associated goals. Each element was addressed through implementation programs such as the award-winning Clean Air Action Plan and Water Resources Action Plan. Stringent soil re-use standards have been established as have beneficial reuse programs for marine dredge sediments. An extensive Community Outreach Program has engaged the Port's constituency through such events as Let's Talk Port, the Green Port Fest and community harbor and rail tours. In conjunction with the Water Resources Action Plan, stringent environmental standards have encouraged the restoration, preservation, and vitalization of marine life within the harbor. To address sustainability, the Port established the cross-divisional Sustainability Task Force in 2005 to encourage adoption of this ethic by staff as an integral part of port operations. Sustainability was formalized into the structure of the Port by the creation of a full-time Manager of Sustainable Programs position in 2008. It was soon recognized that adaption of sustainability in the capital development program would make a major contribution to fully integrating this ethic into the Port and its operations. From this the engineering staff developed sustainable project development guidelines.

Port Sustainability Infrastructure Guidelines. An outcome of the Green Port Policy and the Ports' goal to improve sustainability was its development and implementation of sustainable design and construction guidelines in 2011. The guidelines were designed to be an objective measure of implementation progress and to be a knowledge capture tool. They were built upon a set of sustainable development strategies that was designed to adapt as sustainability knowledge increased. The guidelines capture specific strategies applied to a project that can be built upon for future projects. In this way, the growth and progress in applying sustainability to projects is captured, measured, and reported. The guidelines also measure the balance achieved on a project between the three aspects of sustainability: the environment, economic benefits, and community enhancement, thereby providing an objective measure of a project's sustainability achievements. The guidelines were targeted specifically for the port environment, as no such guidelines were available at the time, and are set up for specific project types.

BACKGROUND

Site History. The project was located in the Wilmington District of Los Angeles, California. It borders the Cerritos Channel to the south, the East Basin to the west, the Consolidated Slip to the north, and the Terminal Island Freeway to the east, as shown in Figure 1.

© ASCE 2014

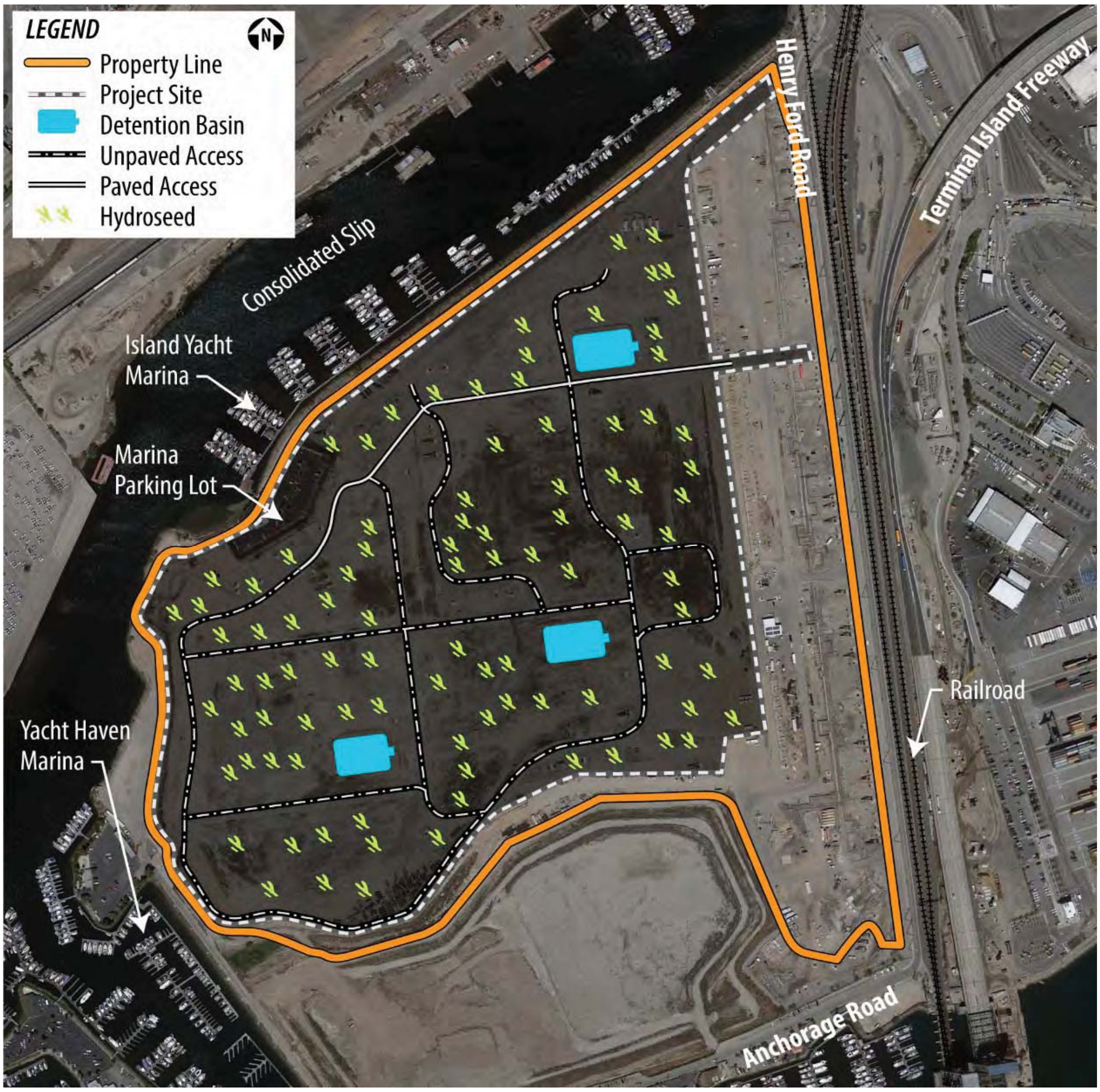


Figure 1. Project Site

The Site has been used for oil production and operations since the 1930s and sits atop the Wilmington Oil Field (one of the largest oil-producing fields in the United States). While under private ownership, from 1948 to 1970, various industrial liquid wastes not conforming to the site disposal permits were disposed of in 19 shallow, below-ground sumps. These wastes included drilling mud, solvents, spent catalysts, paint sludge, and other liquids. In 1970, disposal was terminated and the sumps were covered with 2 to 3 feet of clean soil.

In 1994, the Port purchased the site from Union Pacific Resources Company and leased it to Tidelands Oil Production Company to conduct oil operations. It continues to be used for that purpose today.

Since 1994, the Port has conducted environmental assessments, numerous soil investigations of the sumps, and groundwater investigations of the site. Two contaminated groundwater plumes were identified. The primary contaminates of concern were various volatile organic compounds and total petroleum hydrocarbons. Other contaminates found in the plumes were semi-volatile organic compounds,

© ASCE 2014

polycyclic aromatic hydrocarbons, organochlorine pesticides (such as DDT), polychlorinated biphenyls, and dissolved metals.

In 2001, the Port entered into a Voluntary Cleanup Agreement (VCA) with the California Environmental Protection Agency Department of Toxic Control Substances (DTSC). The DTSC provided oversight for the remediation actions of the on-site materials. From 2002 to 2005, the Port completed remedial investigations and a feasibility study to determine various alternatives for remediation. Of the various alternatives outlined in this study, two soil remediation alternatives and three water treatment alternatives were chosen for further consideration. Then, in 2006, Tide Lands Oil Production Company was acquired by Occidental Petroleum, which took over operations.

On 29 June 2007, during its work through the VCA and in accordance with California Water Code, the Port submitted a request for regulatory oversight to the Los Angeles Regional Water Quality Control Board (Control Board). In response to the request, the Control Board issued a Cleanup and Abatement Order on 27 July 2007. Because of the nature of the contaminants, removal and disposal of all sump material in an approved landfill was chosen as the best alternative to meet the remediation action requirements and prevent future contamination. Contaminated groundwater was treated by a multiphase extraction process and using granulated activated carbon vessels.

Project Description. The main elements of the remediation project included several items. 422,500 tons of sump material from 19 sumps was removed and sent to appropriate landfills. A multiphase extraction system was implemented to remove contamination from ground water. Additionally, the grade of the site was increased to 8 feet above mean lower low water for drainage of stormwater runoff using 1.32 million tons of imported clean fill from Port stockpiles and other regional sources. This included construction of surface drainage systems and detention basins for control of stormwater runoff. Finally, native, drought-tolerant, vegetative cover was planted for erosion and fugitive dust control.

Although there are no future plans to change the current use of the site, which is zoned for heavy industrial use, the Port had considered the site for future container operations. This redevelopment is unlikely in the near future because of the prohibitive costs to improve the strength of the soils for operational requirements. In accordance with state law, the tidelands can only be used for harbor, commerce, navigation, or fisheries. The California Coastal Act restricts the use of the Harbor District, which contains the Site, to commercial port use.

EVALUATION METHODOLOGY

The goal of the study was to evaluate Envision as a tool the Port could use to help shape future business and development practices. Envision was used to determine how sustainability has been implemented on Port infrastructure projects. The rating was based on actions taken by the project team and the outcome of the project through a review of all available project information (e.g., studies, reports, drawings, and specifications) and interviews with the project team. Project information was categorized based on relevance to each Envision credit. An evaluation of each credit

© ASCE 2014

was done to determine applicability to the project. The level of achievement for each applicable credit was determined and the total score was calculated based on the percentage of applicable points achieved.

Because Envision did not exist at the time of the project, the documentation required by the Institute for Sustainable Infrastructure (ISI) for third-party verification was not readily available. When documented information was not available, accounts of the project from the project team were used to the extent practical. Consequently, the rating provided only represents what could be achieved if all information required by the ISI for third-party verification could be produced, submitted, and approved.

RESULTS

The Project was shown to have effectively achieved 24 percent of the applicable points (167 out of 685) within Envision. This would meet Envision's bronze level of recognition. The Project's performance across all five Envision categories is shown in Figure 2. The performance of the Project within each Envision category is provided along with a brief description of the scope of each category.

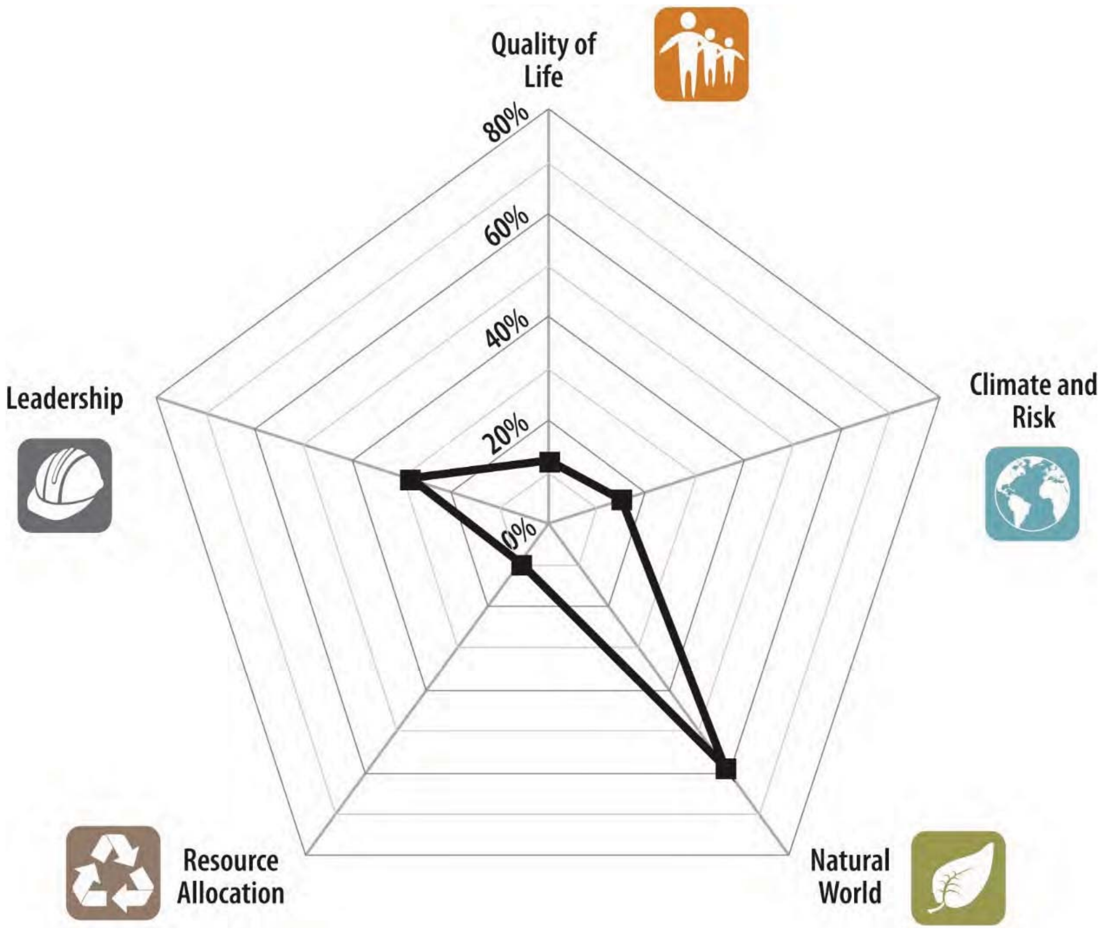


Figure 2. Envision Performance

© ASCE 2014

Quality of Life. The project achieved 12 percent (16 out of 135) of the applicable points for this category as shown in Figure 3.

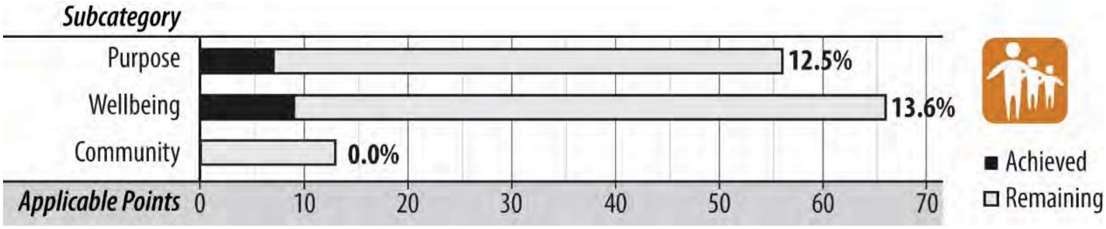


Figure 3. Quality of Life Performance

The main goal of the Project was to remove hazardous contamination; therefore, points were achieved for improving the surrounding community's quality of life and allowing the oil field, a contributor to the local economy, to continue operating (addressing credit QL 1.2). Its success can be contributed to the Port's active engagement with the surrounding marinas and other stakeholders which address credit QL 1.1. The project team took steps to measure noise generated by the remediation project (QL 2.2). They were not allowed to increase ambient conditions more than 5dBA near residences for an extended period of time. (This was critical as many people reside in the marinas adjacent to the site.) Finally, an extensive traffic control plan was established to minimize congestion, a major concern for marina residents during construction (this relates to credit QL 2.4).

Leadership. The project achieved 27 percent (32 out of 113) of the applicable points for this category, shown in Figure 4.

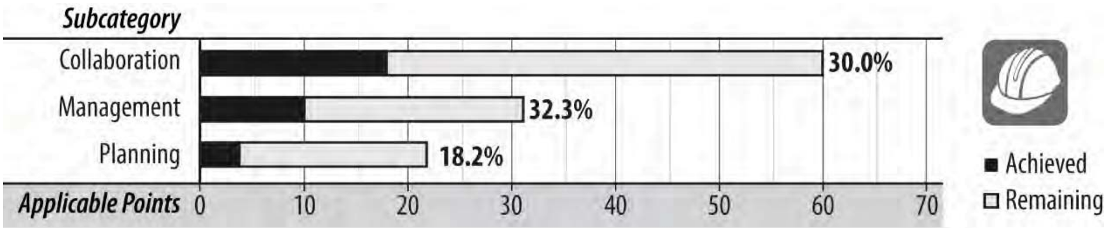


Figure 4. Leadership Performance

Most of the points awarded in this category came from the Port's proactive approach to sustainability which begins with its Green Port Policy (addressing QL1.1). Due to the purchase agreement and the type of contamination found at the site, the Port made an uncommon decision to request a cleanup and abatement order from the Control Board to accelerate the cleanup progress. Additionally, the project team effectively coordinated with a large number of stakeholders. All of the credits within this category were addressed to varying degrees. The complex yet efficient stormwater runoff treatment system, described in the section titled "Natural World," addresses how infrastructure systems can be integrated. This is in line with credit LD 2.2.

Resource Allocation. The project achieved 9 percent (16 out of 170) of the applicable points for this category as shown in Figure 5.

© ASCE 2014

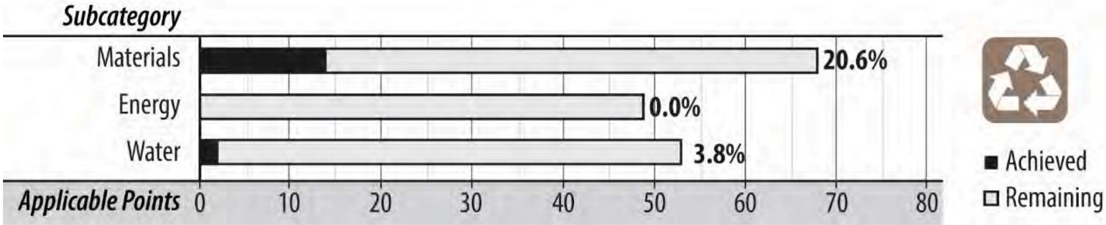


Figure 5. Resource Allocation Performance

Points achieved in this category came from the use of recycled and regional material. All of the soil and aggregate brought to the site was from sources within 50 miles (addressing credit RA 1.4). The specifications also mandated that some of the existing soil be reused and that material from a Port owned soil stockpile be used. The facility also has the ability to use collected stormwater for oil well injection, which reduces potable water use. Additionally, more points may be achieved if additional information on the oil field operations were available with regard to energy use and amount of energy provided by solar panels.

Natural World. The project achieved 59 percent (85 out of 145) of the applicable points for this category as shown in Figure 6.

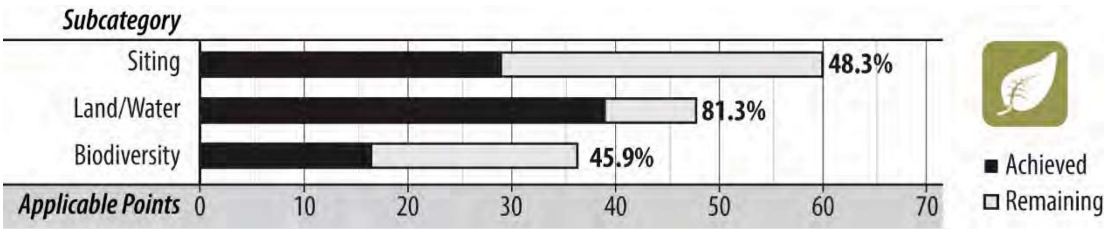


Figure 6. Natural World Performance

Because of the nature of the project (site remediation), more than half of the available points for the Project were achieved. Improving the conditions of a highly contaminated site to a level necessary for its continued safe use through remediation (credit NW 1.7), re-use of all stormwater runoff (NW 2.1 and 2.2), and restoring the soils to support native and drought tolerant plants achieves (NW 3.3) "restoring" marks in four credits for this category. Specific sustainable strategies included bioswales and permeable pavement in the marina parking lot. These infiltrate storm water before it reaches the local channels. Lined catchments in the operating oilfield areas collect stormwater for re-use in subsidence control by deep well injection.

Climate and Risk. The project achieved 15 percent (18 out of 122) of the applicable points for this category, shown in Figure 7.

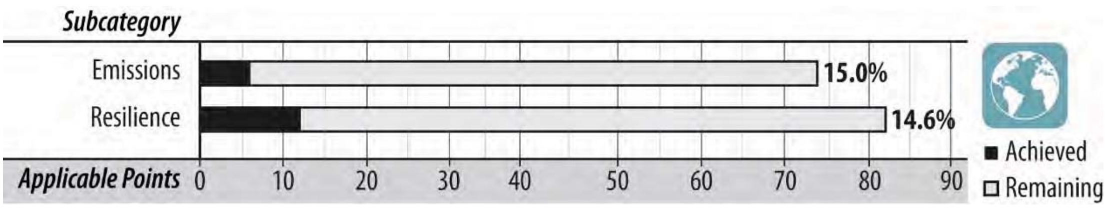


Figure 7. Climate and Risk Performance

© ASCE 2014

Points in this category came from three credits for reducing air pollution through the South Coast Air Quality Management District permits (CR 1.2), ensuring that issues with floods and earth quakes are mitigated through operations and physical barriers (CR 2.4) and removing unnecessary asphalt surfaces that perpetuate the heat island effect (CR 2.5).

CONCLUSIONS

As expected, most of the points for this project came from Envision's Natural World and Leadership categories. By their nature, remediation projects can attain many restorative levels within the Natural World category. The Port has made strong commitments to operating sustainably to improve the quality of life for its community, improve the environment, and support a strong regional economy. To accomplish its goals, it actively engages stakeholders, reviews its operations, and seeks advice from other organizations to improve their performance, as evidenced by this study.

The remaining three categories did not score as well because the project did not start with Envision goals in mind. For many credits, actions specific to the Envision system are not traditionally performed or documented (e.g., LD1.1 requires a written commitment by the project owner and project team to address the economic, environmental, and social aspects of the project). Some of the credits could not be fully evaluated because information on the operations of the oil field was not available. The added benefit of using Envision guidelines is that it helps the project team address other issues related to the project that affect its outcome and long-term success.

Envision and the Port's Sustainability Guidelines. While there are differences in the approach between Envision and the Port's proprietary guidelines, they both accomplish the same purpose by fostering sustainability and capturing past performance to inform delivery of future projects. The most significant difference is that the Port's guidelines are project-centric and port and maritime specific while Envision is designed to be applicable to all infrastructure projects. Where the maritime-specific focus of the Port's guidelines would appeal more to the agency engineering staff, the broader approach and potential wider acceptance of Envision could make it more authoritative to the Port's constituency and other close observers. The Port is currently considering how both standards can be integrated to support the development of sustainable port projects.

Recommendations. To provide a better understanding of Envision rating system, several actions are presented below that could increase the sustainability, and be coincident with Envision rating of this or similar types of projects. Had Envision been available to the project team at the concept stages of the project, it is very likely that many of the actions could have been implemented or documented. Furthermore, it would not likely take a considerable amount of effort to achieve higher levels within Envision by implementing certain strategies. While the project attained 167 of the applicable points, enough for the bronze level of recognition, the following actions

© ASCE 2014

could have added 159 points (a 96 percent increase) for an overall score of 47 percent. This would be sufficient for the gold recognition level.

Category	*Summary of Actions*	*Possible Additional Points*
Quality of Life	More active and documented community engagement (include responses by project team to questions and comments), determine true lighting needs of the site to reduce lighting needs, and include improvements to existing public space or create new public space.	36
Leadership	Provide a commitment by the project owner and project team to consider the aspects of the triple bottom line for the project. Create a plan-do-check-act process that is project specific and considers the triple bottom line. Work with the site operator to monitor water and electricity use, vegetation conditions, and use of stormwater.	41
Resource Allocation	Specifications that require recycling of existing concrete, steel, and asphalt and using a minimum amount of recycled materials (where appropriate).	15
Natural World	Establish a buffer zone at the shoreline to prevent development and reduce impacts from the site on the adjacent waterway. Create habitat in the buffer zone.	37
Climate and Risk	Create a Climate Impact and Assessment report and use it to make decisions at the site and for operations. Use lighter colored (high SRI) pavements or use trees for pavement shading to reduce the heat island effect.	30

Lessons Learned. In addition to the recommendations above, the following general information regarding the use of Envision and increasing sustainable performance is provided.

- Envision can provide a way to track sustainable performance of a facility over its life. By taking "snapshots" after a period of time, during a large project, or after a series of smaller projects, the Envision rating of a facility could be documented and tracked. Based on the site's previous state it is easy to deduce that the project significantly improved the natural and built environments of the site; the Envision rating system helps confirm this.

- Breaking down the Envision rating into subcategories provides a good way to show how various areas of sustainability are being addressed by the project. This can be used to increase sustainability in a particular area and overall performance of the facility.

- Facility maintenance and operations need to be included in the sustainability evaluation of the project. The operations and maintenance of the facility has a large impact on sustainability.

- Investigate ways to incorporate renewable energy sources to the fullest extent possible. Investigate options targeted at reducing energy consumption.

- Consider waste streams of the facility. Find ways for "waste" material to be reused by another facility.

© ASCE 2014

- Monitor the facility throughout its life and determine its efficiency for meeting original design goals. Provide a means to correct issues as they arise.

- Use recycled material to the greatest extent possible (where overall performance will not be compromised). Reuse onsite materials or from nearby facilities to reduce costs and construction transportation needs.

REFERENCES

BergerABAM. (2013). *Pier A West Remediation Envision Evaluation Report.*

City of Los Angeles, Office of Zoning Administration. (2007) *Notice of Public Hearing Fact Sheet.*

Hadfield et al. (2010). "Remediation of an Active Oilfield in a Port Environment," *PORTS Proceedings.*

Institute for Sustainable Infrastructure. (2012) *Envision Guidance Manual, Version 2.0.*

Los Angeles Regional Water Quality Control Board. (2007) *Pier A West/Area 2 Interim/Source Removal Action Cleanup and Abatement Order.*

McDonough and Braungart. (2002) *Cradle to Cradle: Remaking the Way We Make Things.* New York: North Point Press.

TetraTech. (2005). *Final Feasibility Study Report for Pier A West/Area 2.*

URS Corporation. (2007) *Soil Mitigation and Excavation Management Compliance Plan Application Package Supplement.*

URS Corporation. (2008). *Standard Urban Stormwater Mitigation Plan.*

http://www.polb.com/environment/green_port_policy.asp. Port of Long Beach. Green Port Policy website.

Port of Long Beach.(2005). White Paper: "Long Beach Harbor Department Green Port Policy." http://www.polb.com/civica/filebank/blobdload.asp?BlobID=2268

Port of Long Beach. (2006). *Port of Long Beach Strategic Plan 2006-2016.* http://www.polb.com/about/plan.asp

Port of Long Beach. (2008). *Pier A West/Area 2 Interim/Source Removal Action As-Built Plans.*

Port of Long Beach. (2012) *Pier A West Pilot Sustainability Checklist.*

Yarmy and Sereno.(2011). "Port of Long Beach Sustainable Design and Construction Guidelines," ASCE, *Coastal Engineering Practice Proceedings*: pp. 1020 – 1033.

© ASCE 2014

Envision as Choice Architecture: Can Smarter Defaults Lead to More Sustainable Designs?

Tripp Shealy[1] and Leidy Klotz, Ph.D. [2]

[1]Ph.D. Candidate, Glenn Department of Civil Engineering, Clemson University, 131 Lowry Hall, Clemson, SC 29634; email:eshealy@clemson.edu
[2]Associate Professor, Glenn Department of Civil Engineering, Clemson University, 208 Lowry Hall, Clemson, SC 29634; email: leidyk@clemson.edu, website: www.essoresearch.org

ABSTRACT

Like any decision making framework, the Envision rating system has embedded "choice architecture"; for instance, some options are presented before others, options are grouped together, and some are even pre-selected. Whether intentionally designed to do so or not, choice architecture influences the decisions which are made. In our research, we are examining how Envision's current choice architecture, as well as adjustments to it, might help infrastructure stakeholders choose more sustainable options. In this paper, we draw from behavioral science literature to describe and categorize choice architecture in Envision. We then explore whether changes to defaults, one form of choice architecture, may impact design outcomes. The current default in each category of Envision is zero points, and projects can earn points by improving upon industry norms. We hypothesize that a more ambitious default will lead to higher point scores and a more sustainable design. Our rationale is supported by query theory, in which choices are made based on a linear series of questions and these questions are dependent on the starting point, or default. Research in behavioral economics and consumer decisions have shown that simply changing defaults can lead to drastically different decisions. In this paper, we share our methods and preliminary findings from the study of defaults. Then we describe other choice architecture interventions, which warrant further study as they may influence decisions made using the Envision rating system.

INTRODUCTION

Architects recognize that the size, shape, and materials of a building determine how users interact with the space; just as there is no neutral building architecture, there is no neutral choice architecture. Presenting options before others, grouping options together, pre-selecting choices, or framing attributes as positive or negative all are examples of choice architecture, which can influence the decisions made[1].

Choice architecture theory is being applied to improve decision processes in fields from medicine to law to finance (e.g., organ donation, tort law, retirement

[1] For more on choice architecture methods see (Johnson et al., 2012; Thaler & Sunstein, 2008).

© ASCE 2014

savings) [2]. We ask: how can these same choice architecture theories improve decision processes in infrastructure development (e.g., planning and design of roads, water systems, ports, and electricity grids)? The engineers, architects, contractors, and other groups who design and build infrastructure systems commonly rely on infrastructure planning tools and one of these tools is the Envision rating system. Envision is used to evaluate, grade and reward construction projects for meeting sustainability criteria such as reductions in greenhouse gas emissions, preservation of wildlife habitat, and accessibility to community cultural resources.

Inherently, embedded within the Envision framework is choice architecture: credits are partitioned into categories, achievement levels are associated with points, and points are supported by detailed descriptions instructing how to reach higher levels. These features create a choice architecture that organizes the decision making framework.

BACKGROUND: ENVISION AS A CHOICE ARCHITECTURE TOOL

In our research, we are looking for opportunities to enhance Envision's current choice architecture to help infrastructure stakeholders choose more sustainable options. However, the Envision system already applies established choice features, which should improve the decision process.

Partitions improve the decision making process. When presented with too many options, people can become overwhelmed, indecisive, unhappy, and even refrain from making a choice—a phenomenon called choice overload (Iyengar & Lepper, 2000). Grouping decisions by features and presenting questions in a linear framework are shown to reduce these feelings produced by choice overload and reduce the time needed to make a decision (Fox & Langer, 2005; Martin & Norton, 2009). Each choice within the given partition will likely receive the same amount of decision time and weighting (Levav, Heitmann, Herrmann, & Iyengar, 2010).

Envision groups 60 credits into 5 categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk. These categories are again divided into subcategories and related credits are linked together. Partitioning credits provides a systemic method to navigate the system, which possibly reduces choice overload. Rather than seeing all 60 credits at once (each with approximately 5 levels of achievement for a total of 275 decisions), users have a limited vantage point, seeing only one partitioned category at a time. Partitions are also likely to balance users' time and decision-weight between categories. For instance, features like climate risks, which typically receive little consideration in project planning, may now receive equal consideration to features like resource allocation or project finance risk.

Overcoming status quo bias through a reward system. Status quo bias is the reluctance to change one's current position. In Pennsylvania, the status quo for auto insurance is the "Full Right" to sue and challenging the status quo means asking for

---

[2] Organ donation see (Johnson & Goldstein, 2003); Tort law see (Johnson, 1993); retirement savings see (Madrian & Shea, 2000).

© ASCE 2014

"Limited Right" to receive a discount. In New Jersey, "Limited Right" represents the status quo and policyholders must actively ask for "Full Right." Johnson et al (1993) showed that the reluctance to break status quo meant 75 percent of Pennsylvania motorists obtained "Full Right" while only 20 percent in New Jersey. This difference translates to more lawsuits filed in Pennsylvania (Fischhoff & Kadvany, 2011).

Envision creates a reward system through level of achievement points that encourage users to overcome the status quo. Plans that keep with the industry norm (status quo) receive no points while plans to achieve the *restoring* level receive the highest score. Moving away from the industry norm is perceived as a risk, or a threat to the status quo. Giving points creates a high-risk, high-reward scenario. These points translate into real world value, such as in the form of public recognition or possible monetary bonuses from owners. Table 1 is an example of how users navigate the credit, rating, and point systems.

Table 1: Example of Credit Rating and Order of Achievement Levels

NW2.3 PREVENT SURFACE AND GROUNDWATER CONTAMINATION				
INTENT: Preserve fresh water resources by incorporating measures to prevent pollutants from contaminating surface and groundwater and monitor impacts over operations. METRIC: Designs, plans and programs instituted to prevent and monitor surface and groundwater contamination.				
LEVELS OF ACHIEVEMENT				
IMPROVED *Possible points: 1*	*ENHANCED* *Possible Points: 4*	*SUPERIOR* *Possible Points: 9*	*CONSERVING* *Possible Points: 14*	*RESTORING* *Possible Points: 18*
Design for response.	Long term monitoring.	Design for prevention.	Design for source elimination.	Remediate existing contamination.

Detailed descriptions increase confidence. Past experiences, or subject knowledge, can inform current decisions. However, this can lead to overconfidence in judgment of risk. For example, someone knowledgeable in football will feel more confident about predictions in obscure football events than in gambles of chance (such as a coin toss), even when the probabilities of both are exactly the same (Fox & Tversky, 1998; Heath & Tversky, 1991). To shift cognitive focus away from decisions based on experience, choice architects can provide more detailed descriptions of the options they want users to consider (Erev, Glozman, & Hertwig, 2008; Khaneman & Tversky, 1979). In essence, the extra description changes how information is collected from within the brain.

When engineers use previous construction knowledge to justify current project performance, this is an example of how current decisions are informed by the past. If these past decisions kept with the industry norm, this can create a reluctance to depart from these norms and underweight novel design solutions (Beamish & Biggart, 2010). Envision shifts decision weighting from experience to description by prompting users with questions about how the design team plans to explore new

© ASCE 2014

options. For example, "Has the project team identified and assessed possible changes in key engineering design variables?" ("Envision™ Sustainable Infrastructure Rating System," 2012). To answer these questions, Envision provides documentation and links to technical details of engineering design. This added information might improve user confidence levels and motivation to create new designs that meet longer-term objectives.

While partitions, points, and details create an Envision framework that guides users during the decision making process, we believe more can still be done to encourage the highest levels of Envision achievement—in particular meeting *conserving* and *restoring* goals. In the next section, we explore whether changes to one type of choice architecture, defaults, may impact design outcomes. Each category of Envision begins at a default of zero points, and infrastructure projects can earn points by improving upon industry norms. We study whether a more ambitious default, set to *conserving* (four levels above the current default), will lead to higher point scores. Users, who uphold the default, keep the points at the *conserving* level. While users that move to the industry norm lose the endowed points and receive a score of zero. Changing the default option can shape users' preferences about sustainability choices differently and, as a result, infrastructure projects can achieve higher points. We explain how these user preferences are constructed.

Defaults as a choice architecture. While there are many choice architecture strategies, we focus here on defaults to construct user preferences about infrastructure planning options. Our rationale is supported by query theory, in which choices are made based on a linear series of questions and these questions are dependent on the starting point, or default (Johnson, Häubl, & Keinan, 2007). Initial questions produce longer richer responses than later questions and, subsequently, this impacts the outcome (Weber et al., 2007). Defaults influence the linear series of questions in three ways: *effort, endorsement,* and *reference dependence* (Dinner, Johnson, Goldstein, & Liu, 2010). *Effort* suggests the cognitive energy associated with the decision making task. Employees who do not select a 401(k) plan, displaying a lack of *effort* to make a decision, still save money because of a predetermined default of 3 percent annual investment (Madrian & Shea, 2000). *Endorsement* means decision makers may perceive the default as the recommended option because it reflects the most commonly chosen or fits within the social norm (Brown & Krishna, 2004; McKenzie, Liersch, & Finkelstein, 2006). Shoppers who believed a manufacturers default product option was selected in earnest, representing the best features and not solely the most expensive, were more likely to stay with the default option (Brown & Krishna, 2004). *Reference dependence* means the default frames the outcome as a loss or gain and this frame impacts the decision (Dinner et al., 2010). Car buyers first shown the "fully loaded" package perceive lesser models as having lost features (Park, Jun, & MacInnis, 2000). Meanwhile, car buyers first shown the base model perceive those same features as add-ons. This feeling of loss or gain is reference dependent on the starting point.

As currently arranged, Envision rewards a project 4 points *(improved)* by reducing water consumption by 25 percent and 17 points *(conserving)* for 100 percent reduction. However, by giving points for slight improvements, Envision may unintentionally discourage the even higher levels of sustainability performance that

© ASCE 2014

are possible. Shifting the default from industry norm to *conserving* may encourage higher levels of achievement. In our revised scale, additional points are only possible by achieving the highest level, one step above the newly set default. Achieving below the default will result in a loss of points. Now, a 25 percent water reduction subtracts 13 from the 17-point default rather than adding 4 to 0. This method endows value (points) to users and restructures the internal mental questioning used in the decision making process. The *conserving* level of achievement is chosen as the new default because it represents the environmental neutral; meaning the infrastructure development plan neither harms nor improves the surrounding community or environment—the bare minimum requirement for true sustainability.

Effort. Envision requires an active choice (or *effort)* for every credit. Therefore, *effort* is limited to the form of satisficing, which is when users accept a lower reward for instant gratification rather than apply more effort to reach higher achievement (Weber et al., 2007). To reach the highest level of sustainability in Envision with the current industry default requires answering over 250 questions. With this many questions, users may act to satisfice, choosing to answer fewer questions and accept lower achievement.

Changing the default to *conserving* will decrease satisficing. Following a transitive framework, every point within Envision builds on the next. By orienting users closer to the middle of the scale, rather than at the beginning, users can move up or down from the default and more easily identify the level of achievement suitable for them. Loss averse users will increase effort not to loose points already given.

Endorsement. Just as a zero percent investment for retirement sets a low benchmark, the Envision default preserves an undesirable *endorsement* for low achievement (Sunstein & Thaler, 2003). Moving away from the industry norm is accompanied by higher perceived risk and this added risk could limit users' willingness to achieve higher points.

A *conserving* default will endorse a more sustainable, higher achieving social norm. When people value different outcomes, they define risk differently. By endorsing the *conserving* level as the social norm the perceived risk of achieving a higher score will diminish. This will increase user confidence and motivation to maintain the new *conserving* benchmark.

Reference Dependence. Envision users gain points. Given a low reference (zero points) with nothing to lose they are told to add towards a sustainable infrastructure plan. Khaneman and Tversky (1979) showed that a loss provokes greater degrees of discomfort than a gain provides satisfaction. The differences between loss or gain is physically measured in fMRI brain scans (Gonzalez, Dana, Koshino, & Just, 2005; Yi-Rong et al., 2011). Shifting Envision users from a point gain to a point loss frame may lead to higher motivation trying to avoid the discomfort felt by a loss.

The *conserving* default will act as an endowment. Users will construct preferences based on this new reference and increase their perceived value of points. This follows the classical hypothesis that people owning an item value its worth twice as much than if they did not own the same item (Thaler, 1980). The effect takes little

© ASCE 2014

time to establish (Khaneman, Knetsch, & Thaler, 1990), and we suggest that simply changing the default may be enough to promote higher scores.

Our hypotheses builds on previous judgment and decision making studies, but differs in several ways: we set a default with points, rather than product features which may lead to different outcomes or perceived value. Envision users are not choosing options about a product for purchase, but rather to influence a physical design, and this may cause users to construct preferences differently than previous studies suggest. We are asking questions with multiple attributes, meaning users are choosing between 5 options, not just opt-in or opt-out choices. This may alter the degree of influence of the default option on the decision maker. Finally, this is the first study examining engineers' decision making by varying choice architecture. In the conclusion, we detail future studies with Envision and suggest a path for other researchers to examine choice architecture of additional engineering planning and design tools.

EXPERIMENTAL APPROACH & FINDINGS

During a 30-minute lecture, students learned about Envision's purpose, how to navigate, and use the rating system to select project features. Students were told they represent the "sustainability coordinator" for a project team designing an outdoor community center and stream restoration on a 0.4-acre brownfield site in rural Alabama. Students were given the site's Environmental Assessment and community revitalization plan to make informed decisions, like how to clean site contamination, restore stream water quality, and orient the outdoor community center. The Envision rating system prompts participants' decisions with each credit question. For example, Credit NW 2.1 asks if Low Impact Development (LID) guidelines were used to reduce storm water runoff. Participants explained if and how LID was incorporated and how this translates to level of achievement points.

To control for students selecting the highest level of achievement without considering design impacts we created a cost-benefit scenario: the higher the level of achievement, the longer the written explanation. Meeting *conserving* level of achievement requires a longer explanation than meeting the *improved* level of achievement. To reduce the amount of time to complete the assignment, we only included two out of the five categories: Quality of Life and Natural World (26 of the 60 available credits). Removing Leadership, Resource Allocation and Climate and Risk reduced the need to include life cycle assessment and project team management information in the case study.

Our rating system randomized participants, giving a 50/50 chance, to receive the standard version, starting at industry norm with zero points, or *conserving* level of achievement, starting with 304 points, out of a possible 384 points. . Students were told their starting number of points but were unaware another version existed. Our software captured scores and written explanations. We measured the mean difference in scores between groups and the time to complete the rating process. Preliminary results indicate the 304-point default compared to the 0 point default led to a higher project score. The 304-point default group believed more credits were applicable to the project and scored higher in each category. Yet, the majority of students believed the default did not affect their decision making process. Further analysis will indicate

© ASCE 2014

if the conserving group correlates to increased motivation. Those not meeting the *conserving* level default may view the rating system differently than those who did. Follow up responses will provide evidence if those losing points viewed the rating system negatively or if the *conserving* default group viewed achieving a high score as easier than the industry norm group.

Previous research presents conflicting evidence that novice and expert engineers use the same decision making patterns (Ahmed, Wallace, & Blessing, 2003; Kiziltas, Akinci, & Gonzalez, 2010). Student engineers often lack the experiential knowledge that professional engineers use in making decisions (Wang & Leite, 2014). We are replicating this study with an industry professional group to identify similarities and differences in decision making between novice and expert engineers. We hope results will support past research that shows experts are just as susceptible to choice architecture as novices (Fatas, Neugebauer, & Tamborero, 2007). Follow-up surveys will identify how industry groups construct internal questions and if these keep with query theory.

CONCLUSION

Defaults are a specific type of choice architecture that determines the initial way users encounter options. Simply pre-checking a box is a powerful first impression. Private retirement plans with defaults set to invest increase user savings (Cronqvist & Thaler, 2004; Madrian & Shea, 2000). Online shoppers purchase more expensive items when multiple product options are available and set to the highest priced default option (Herrmann et al., 2011). Preliminary results indicate civil engineers can be added to the list of decision makers influenced by choice architecture. Further analysis of student results and the current industry study can add more evidence. However, the difference between previous studies and ours is that civil engineers are not consumers but trained professionals whose decisions during planning influence physical infrastructures, which in turn affect the energy use of end-users for a long period of time. Changing the choice architecture of engineering decision-tools is a relatively low-cost method to meet more sustainable infrastructure. Simply adding points for slight improvements unintentionally discourages the higher levels of achievement that are possible. Shifting the default to *conserving* reframes the internal questioning process of the decision-maker and subsequently encourages higher levels of achievement. The unique Envision framework allows for analysis on preference construction by measuring quantitative data in point outcomes, based on a change in value, and qualitative in design verification for each credit.

Broader Implications and Opportunities for Additional Research. America's infrastructure systems must be designed using sustainable practices, ensuring functionality for future generations (ASCE, 2009). This research has the potential to help meet this urgent need. Choice architecture influences up-front planning decisions. Defaults impact design outcomes. Sustainable options are often a deviation from traditional practice, and this deviation creates cognitive barriers in the decision making process (Beamish & Biggart, 2010). Specific to Envision, we list additional choice architecture studies, in Table 2, that hold potential to reduce these barriers and encourage higher levels of achievement. One study, listed below, is a change in commitment framing: For example, Credit NW 3.4 *improved* asks, “Does the project

© ASCE 2014

maintain or enhance one ecosystem function?" By reversing the commitment role, users would now answer why they could not meet the *conserving* default rather than how they met *improved*. The same *improved* credit question would read: "Explain why the project could not maintain or enhance all ecosystem functions" keeping with the *conserving* default. This change in frame strongly implies a higher commitment, and may cause an even higher sustainability achievement.

Table. 2: Future Envision studies to measure choice changes caused by choice architecture

Choice Architecture	Connection to Envision	Envision Intervention
Attribute Framing – The framing manipulation is not the choice, but instead the attribute name or wording of the options. (Levin, Schneider, & Gaeth, 1998).	Each Envision credit includes levels of achievement: *improved - restoring*. The wording itself may provoke a bias in goal setting. For example, *superior* sounds better than *conserving*, yet *conserving* is a higher achieved score.	Change the level of achievement name to a consistent hierarchy scale, (e.g. 1-star, 2-star, 3-star, 4-star, 5-star).
Reversing the scale – Based on Query Theory, the order of questions influences the users' internal questions and impacts the decision (Johnson et al., 2007).	The Envision metrics orders level of achievement options left to right, *improved to restoring*.	Reverse this scale so the most aggressive goal, *restoring*, is on the left, and therefore the first option readers consider.
Commitment – Asking people to commit prior to the task improves completion rate.	Envision asks users how they plan to meet a level of achievement. For example, Credit NW 3.4 *improved* asks, "Does the project maintain or enhance one ecosystem function?"	Reverse the commitment role. Ask users why they could not meet a higher level of achievement.
Social reference – This gives us a comparison to status quo. Energy consumption declines when referenced to neighbors. (Nolan, Schultz, Cialdini, Goldstein, & Griskevicius, 2008)	As more projects become Envision certified, people will become aware of the rankings, similar to LEED.	Use certified projects to set a higher benchmark. For example, tell the Envision user how other projects scored on each credit.

We recognize not all choice architecture methods will move decision makers towards sustainability choices. Some are more powerful than others and choice

© ASCE 2014

effects may vary based on project structure[3]. Also, our study represents a small portion of a larger, on-going study. This paper highlights the connection between behavior science and infrastructure planning. More research is needed to bridge these disciplines. We ask researchers to examine other civil engineering decision tools. For instance, understanding how an engineer constructs preferences about material options when using Building Information Modeling (BIM) could help identify if shifting the order of options, number of clicks or default settings influences a change in choice. Engineers that use Intelligent Transportation System (ITS) software may perceive computer-based models as less risky than other forecasting methods due to the large data sets used to create the computer simulations. Through feedback loops we can identify how these forecasts impact project outcomes and analyze if these high confidence levels are confounded. ITS and BIM are two examples that hold high-impact decisions yet to be examined through choice architecture. We see these studies as primary research needs that hold potential to create more sustainable infrastructure at a relatively low cost to implement.

ACKNOWLEDGMENTS

We would like to thank Elke Weber, Eric Johnson, Edy Moulton-Tetlock, and Ruth Greenspan Bell for their guidance and participation in discussions related to the ideas that contributed to this paper. In addition, this material is based on work supported by the National Science Foundation, through Grant 1054122.

REFERENCES

Ahmed, S., Wallace, K. M., & Blessing, L. T. (2003). Understanding the differences between how novice and experienced designers approach design tasks. Research in Engineering Design, 14(1), 1–11. doi:10.1007/s00163-002-0023-z

ASCE. (2009). 2009 Report Card for America’s Infrastructure. ASCE. Retrieved March 14, 2009, from http://www.asce.org/reportcard/2009/grades.cfm

Beamish, T., & Biggart, N. (2010). Social heuristics: Decision making and innovation in a networked production market. UC Davis Graduate School of Management Research Paper, (01-10). Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1533429

Brown, C. L., & Krishna, A. (2004). The Skeptical Shopper: A Metacognitive Account for the Effects of Default Options on Choice. Journal of Consumer Research, 31(3), 529–539. doi:10.1086/425087

Cronqvist, H., & Thaler, R. H. (2004). Design Choices in Privatized Social-Security Systems: Learning from the Swedish Experience. The American Economic Review, 94(2), 424–428. doi:10.2307/3592922

Dinner, I. M., Johnson, E. J., Goldstein, D. G., & Liu, K. (2010). Partitioning Default Effects: Why People Choose Not to Choose (SSRN Scholarly Paper No. ID 1352488). Rochester, NY: Social Science Research Network. Retrieved from http://papers.ssrn.com/abstract=1352488

[3] See (Levin, Schneider, & Gaeth, 1998) for an overview of choice shift, choice reversal or no effect in various domains and populations.

EnvisionTM Sustainable Infrastructure Rating System. (2012). Institute for Sustainable Infrastructure. Retrieved May 5, 2013, from http://www.sustainableinfrastructure.org/rating/index.cfm
Erev, I., Glozman, I., & Hertwig, R. (2008). What impacts the impact of rare events. Journal of Risk and Uncertainty, 36(2), 153–177. doi:10.1007/s11166-008-9035-z
Fatas, E., Neugebauer, T., & Tamborero, P. (2007). How Politicians Make Decisions: A Political Choice Experiment. Journal of Economics, 92(2), 167–196. doi:10.1007/s00712-007-0264-4
Fischhoff, B., & Kadvany, J. D. (2011). Risk: a very short introduction. Oxford; New York: Oxford University Press.
Fox, C. R., & Langer, T. (2005). Biases in Allocation Under Risk and Uncertainty: Partition Dependence, Unit Dependence, and Procedure Dependence (SSRN Scholarly Paper No. ID 757787). Rochester, NY: Social Science Research Network. Retrieved from http://papers.ssrn.com/abstract=757787
Fox, C. R., & Tversky, A. (1998). A Belief-Based Account of Decision Under Uncertainty. Management Science, 44(7), 879–895.
Gonzalez, C., Dana, J., Koshino, H., & Just, M. (2005). The framing effect and risky decisions: Examining cognitive functions with fMRI. Journal of Economic Psychology, 26(1), 1–20. doi:10.1016/j.joep.2004.08.004
Heath, C., & Tversky, A. (1991). Preference and belief: Ambiguity and competence in choice under uncertainty. Journal of Risk and Uncertainty, 4(1), 5–28.
Herrmann, A., Goldstein, D. G., Stadler, R., Landwehr, J. R., Heitmann, M., Hofstetter, R., & Huber, F. (2011). The effect of default options on choice—Evidence from online product configurators. Journal of Retailing and Consumer Services, 18(6), 483–491. doi:10.1016/j.jretconser.2011.06.005
Iyengar, S. S., & Lepper, M. R. (2000). When choice is demotivating: can one desire too much of a good thing? Journal of Personality and Social Psychology, 79(6), 995–1006.
Johnson, E. J. (1993). Framing, Probability Distortions, and Insurance Decisions. Journal of Risk and Uncertainty, 7(1), 35–51.
Johnson, E. J., & Goldstein, D. (2003). Do Defaults Save Lives? Science, 302(5649), 1338–1339. doi:10.1126/science.1091721
Johnson, E. J., Häubl, G., & Keinan, A. (2007). Aspects of endowment: a query theory of value construction. Journal of Experimental Psychology. Learning, Memory, and Cognition, 33(3), 461–474. doi:10.1037/0278-7393.33.3.461
Johnson, E. J., Shu, S. B., Dellaert, B. G. C., Fox, C., Goldstein, D. G., Häubl, G., … Weber, E. U. (2012). Beyond nudges: Tools of a choice architecture. Marketing Letters, 23(2), 487–504. doi:10.1007/s11002-012-9186-1
Khaneman, D., Knetsch, J., & Thaler, R. (1990). Experiment tests of the endowment effect and Coase theorem. Journal of Political Economy, 98, 1325–1348.
Khaneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. Econometrica, 74(2), 263–292.
Kiziltas, S., Akinci, B., & Gonzalez, C. (2010). Comparison of experienced and novice cost estimator behaviors in information pull and push methods. Canadian Journal of Civil Engineering, 37(2), 290–301. doi:10.1139/L09-152

© ASCE 2014

Levav, J., Heitmann, M., Herrmann, A., & Iyengar, S. S. (2010). Order in Product Customization Decisions: Evidence from Field Experiments. Journal of Political Economy, 118(2), 274–299. doi:10.1086/652463

Levin, I. P., Schneider, S. L., & Gaeth, G. J. (1998). All Frames Are Not Created Equal: A Typology and Critical Analysis of Framing Effects. Organizational Behavior and Human Decision Processes, 76(2), 149–188. doi:10.1006/obhd.1998.2804

Madrian, B. C., & Shea, D. F. (2000). The Power of Suggestion: Inertia in 401(k) Participation and Savings Behavior (Working Paper No. 7682). National Bureau of Economic Research. Retrieved from http://www.nber.org/papers/w7682

Martin, J. M., & Norton, M. I. (2009). Shaping online consumer choice by partitioning the Web. Psychology and Marketing, 26(10), 908–926. doi:10.1002/mar.20305

McKenzie, C. R. M., Liersch, M. J., & Finkelstein, S. R. (2006). Recommendations implicit in policy defaults. Psychological Science, 17(5), 414–420. doi:10.1111/j.1467-9280.2006.01721.x

Nolan, J. M., Schultz, P. W., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2008). Normative Social Influence is Underdetected. Personality and Social Psychology Bulletin, 34(7), 913–923. doi:10.1177/0146167208316691

Park, C. W., Jun, S. Y., & MacInnis, D. J. (2000). Choosing What I Want Versus Rejecting What I Do Not Want: An Application of Decision Framing to Product Option Choice Decisions. Journal of Marketing Research, 37(2), 187–202. doi:10.1509/jmkr.37.2.187.18731

Sunstein, C. R., & Thaler, R. H. (2003). Libertarian Paternalism Is Not An Oxymoron (SSRN Scholarly Paper No. ID 405940). Rochester, NY: Social Science Research Network. Retrieved from http://papers.ssrn.com/abstract=405940

Thaler, R. H. (1980). Toward a Positive Theory of Consumer Choice. Journal of Economic Behavior and Organization, (1), 39–60.

Thaler, R. H., & Sunstein, C. (2008). Nudge: Improving Decisions About Health, Wealth, and Happiness. Yale University Press.

Wang, L., & Leite, F. (2014). Comparison of Experienced and Novice BIM Coordinators in Performing Mechanical, Electrical, and Plumbing (MEP) Coordination Tasks. In Construction Research Congress 2014 (pp. 21–30). American Society of Civil Engineers. Retrieved from http://ascelibrary.org/doi/abs/10.1061/9780784413517.003

Weber, E. U., Johnson, E. J., Milch, K. F., Chang, H., Brodscholl, J. C., & Goldstein, D. G. (2007). Asymmetric discounting in intertemporal choice: a query-theory account. Psychological Science, 18(6), 516–523. doi:10.1111/j.1467-9280.2007.01932.x

Yi-Rong, N., Si-Yun, S., Zhou-Yi, G., Si-Run, L., Yun, B., Song-Hao, L., & Chan, W. Y. (2011). Dissociated brain organization for two-digit addition and subtraction: An fMRI investigation. Brain Research Bulletin, 86(5–6), 395–402. doi:10.1016/j.brainresbull.2011.08.016

© ASCE 2014

Sustainable Pedestrian Bridge Design: A Discussion of the Envision Rating System

C. Huang, PE, MSc, LEED AP BD+C, ENV SP[1]

[1]Arup, 12777 West Jefferson Boulevard, Building D, Los Angeles, CA 90066; PH (310) 578-4603; FAX (310) 861-9029; email: cindy.huang@arup.com

ABSTRACT

A new pedestrian bridge in the City of Long Beach, CA seeks to incorporate sustainable features in the design, but the application of sustainable infrastructure is still undefined. Existing research in this field focuses on calculating embodied energy or embodied carbon, which evaluates sustainability through a strictly environmental lens. A comparison of these criteria to the goals in the Institute for Sustainable Infrastructure's Envision Rating System shows that Envision considers a holistic, system-wide interpretation of sustainable infrastructure. Envision is therefore most applicable for initial high level decision making, such as where to locate the project site or whether to hire local workers for the project, which are societal factors that carbon and energy estimates do not take into account. The ideal project will have an appropriate focus on all impacts of a project to create a balanced design.

BACKGROUND INFORMATION

Long Beach, California is home to world class facilities like the Long Beach Convention Center and Performing Arts Center, which play host year-round to high profile conventions, drawing an estimated 8 million visitors annually. It is in this context that the City of Long Beach has engaged services for the design and construction of a new $5.8 million iconic pedestrian bridge linking the Convention Center and Performing Arts Center. The purpose of the bridge is to enchance accessibility between these key facilities and to increase the volume of foot traffic in this area.

The project is a 400ft long pedestrian bridge located on the north side of Seaside Way that connects the elevated walkway of Convention Center Way to the rooftop of Terrace Theater, which is part of the Long Beach Performing Arts Center. The owner, City of Long Beach, has requested an iconic structure that reflects the cultural and visual context of the surrounding area and demonstrates the sustainability initiatives and goals of the city as it looks to the future.

To fulfill these criteria, the project team, which includes global engineering consultant Arup and locally-renowned architect SPF:a, recognized a unique opportunity to apply sustainable infrastructure design principles. Although the project RFP identifies LEED as the intended sustainability rating system for the project,

© ASCE 2014

LEED is less applicable to infrastructure projects due to its heavy emphasis on energy usage in the operational stage of the project. Instead, the team has decided to explore the applicability of the Institute of Sustainable Infrastructure's (ISI) Envision Rating System, which has only come onto the scene of sustainable rating systems in the past few years.

EXISTING LITERATURE

Research on sustainable infrastructure has grown significantly in the past decade, but still lags behind research on sustainable buildings. Early papers on this subject followed the example set by buildings and explored the definition of sustainability from a strictly energy and carbon metric viewpoint. In one of the first papers on the subject, Martin (2003) studied the environmental impact of different material selections, finding that per kilogram of material, concrete is preferable to steel due to the high energy and resource consumption required during the steel production process. Martin also notes that "practical tools for assessment of sustainability performance of concrete bridges require further development", since at the time of writing no such system as Envision existed.

Building on Martin's foundation, Collings (2006) further studied the sustainability performance of concrete bridges, comparing different bridge forms to find the design with the lowest associated environmental impact. This impact, according to Zhang (2010) is dominated by the initial construction stage of the bridge, rather than during the service life of the structure. This is in stark contrast to the buildings industry, where energy use for operations and maintenance is the main contributor to greenhouse gas or carbon emissions.

In summary, the major conclusions made by extant literature are: a) infrastructure projects are significant consumers of energy and carbon, but b) this consumption occurs primarily during the construction phase, and c) a practical system for measuring the impact of sustainable infrastructure projects has not yet become popular in the industry. In the absence of an appropriate sustainability rating system, existing research has focused exclusively on quantifying the sustainability of bridges through environmental metrics rather than holistic societal impacts.

METHODOLOGY

This paper explores the concept of sustainable infrastructure using a two-fold approach: the first is to grade the design using the Envision checklist; the second is to estimate the embodied energy required to produce the design.

The Envision checklist is a holistic tool provided by ISI for evaluating the project in five categories: Quality of Life, Leadership, Resource Allocation, Natural World,

© ASCE 2014

and Climate and Risk. The user answers a series of "yes" or "no" questions about the project and based on the results, project teams can identify the strongest sustainable sectors of the project as well as the areas that need further attention according to Envision. The checklist is a preliminary tool intended to help decide between alternatives in the early design stage of a project.

The second approach, the embodied energy calculation, is consistent with approaches taken by prior researchers in sustainable infrastructure. Each of the two design alternatives presented in this paper will be evaluated on the embodied energy or carbon per square meter of plan area. The analysis is performed based on total quantities of materials and uses average energy data from Hammond and Jones (2008). Transportation of materials to the project site will also have an impact on the embodied energy, but at this preliminary stage no fabricators have been selected and therefore no transportation data is available.

The rationale for performing both analyses is to provide a side-by-side comparison of the Envision rating system to the embodied energy figures, which are commonly used as a sole metric for evaluating the sustainability of a project.

Since the design of the Long Beach Pedestrian Bridge is still in the preliminary concept stage, this research marks the beginning of a more detailed investigation to come. Envision ISI certification is being considered, but has not yet been implemented for the Long Beach Pedestrian Bridge at the time of writing.

CASE STUDY – Long Beach Pedestrian Bridge

Project description.

This study is performed based on the concept stage design, which is still undergoing revision at the time of writing and is therefore not to be taken as the final design.

The intent of the project goes beyond a walkway connecting point A to point B. It is envisaged by the project team that the bridge will act as a gathering space for the community to rest, congregate, and comingle. The bridge is perceived to be an enhancement to the available public space rather than a single purpose throughway for traveling between buildings. The width of the bridge, which increases from approximately 20ft at the ends to 40ft at its widest point midway, makes it akin to an outdoor terrace. Seating and planting will be provided to encourage people to gather on the bridge. The result is a multipurpose space that can accommodate overflow for events or act as an attractive outdoor event space by itself.

© ASCE 2014

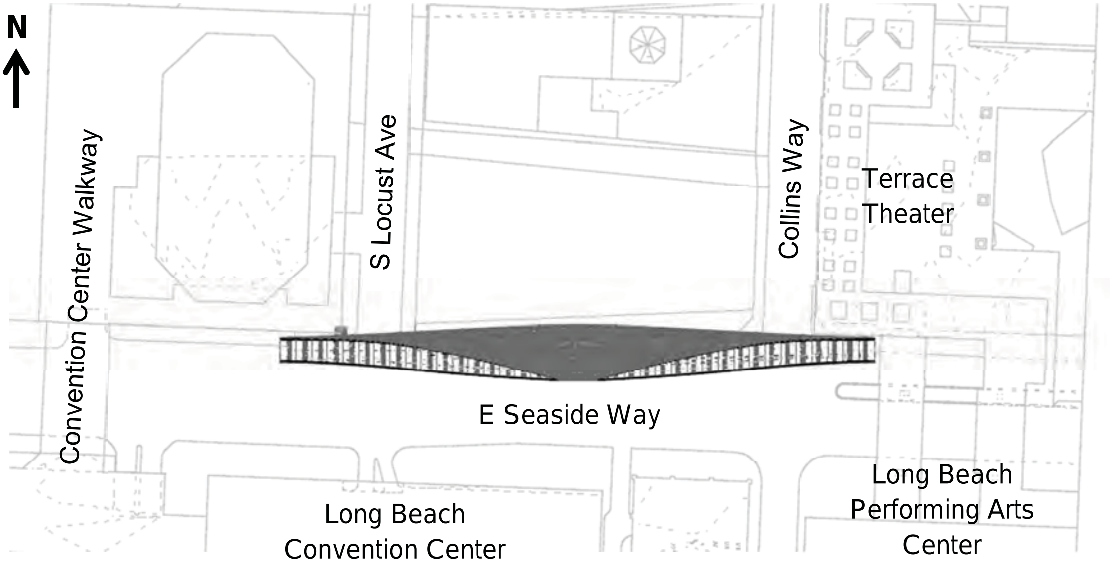


Figure 1 – The pedestrian bridge runs along Seaside Way, connecting the Convention Center and Performing Arts Center.

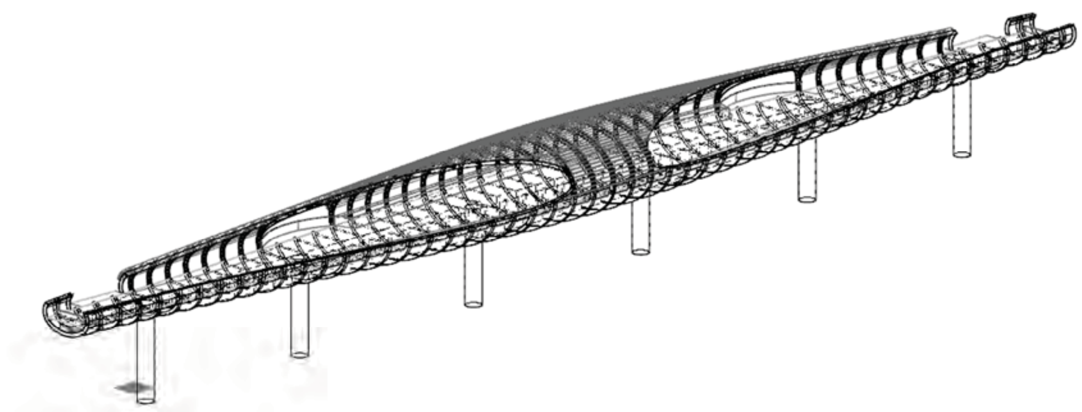


Figure 2 – 3D view of bridge.

The primary components of the bridge that are evaluated in this paper are: the structural elements forming the deck, the substructure elements including bent caps and columns, and the main architectural feature, the canopy that gives the bridge its iconic "rip curl" form.

The choice of material for the bridge is concrete, which is driven by the owner's preference for ease of maintenance. Steel is required for the cantilevered canopy to support loads due to wind, self-weight, and the weight of the canopy cladding.

Immediately north of the project site is an empty lot, which is expected to become a future residential development. To accommodate the future development, the bridge design will incorporate connection points that provide flexibility for the design of the

© ASCE 2014

future building. In addition to providing shade, the canopy will function as a visual and acoustic screen to provide privacy for users of both structures.

Alternative analysis. Two configurations have been evaluated in this paper: the first is the "base" design as initially envisaged in the early weeks of concept design; the second is an "optimized" design that modifies the base design to incorporate sustainable design practices. The plan areas and lengths of the two options are identical.

The differences between these two options are summarized in Table 1.

Table 1. Base Design vs. Optimized Design.

	Base Design	Optimized Design
Construction method	Cast-in-place	Precast elements transported to site
Number of supports	8	6
Canopy configuration	Covers entire structure	Terminates at deck level
Deck cross section	Custom curved multicellular box	Custom curved "ribs"

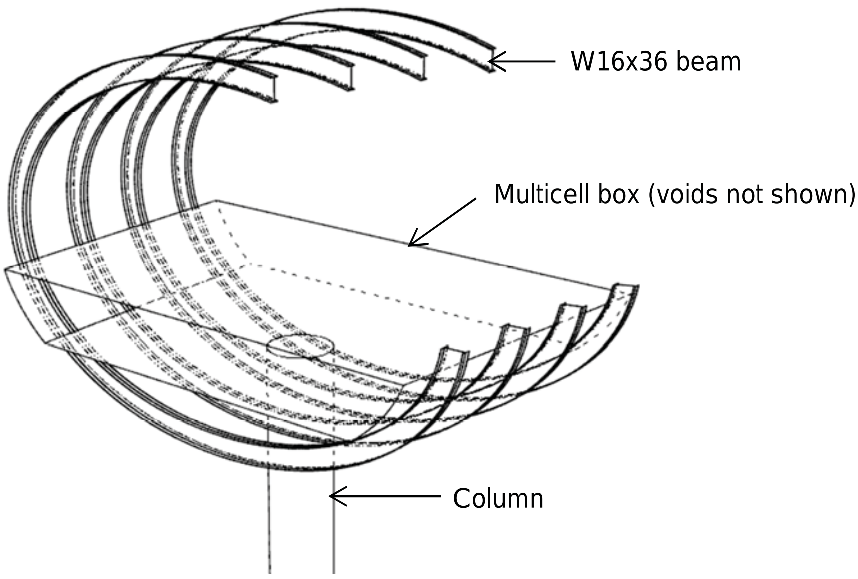


Figure 3 - Typical section of the Base Design. Voids in deck are not shown for clarity.

© ASCE 2014

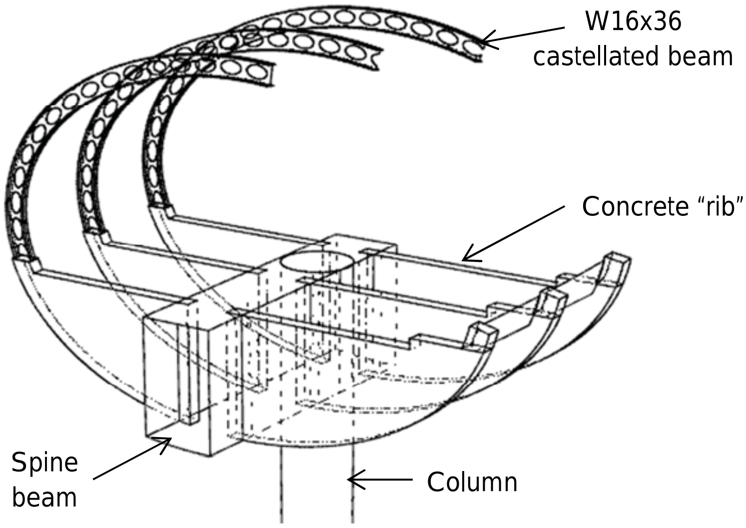


Figure 4 – Typical section of the Optimized Design with concrete rib elements and castellated steel beams.

RESULTS

Part 1 – Envision Checklist.

Table 2 presents the major design changes between the base design and the optimized design that led to increases in the Envision checklist scores.

Table 2. Design changes between base and optimized designs.

Design change	Implication
Switch from cast-in-place deck to precast deck components	▪ Reduction in noise and vibration that would be generated by cement trucks and concrete consolidation equipment [QL 2.2] ▪ Reduced embodied energy since reduction in formwork allows for saving on single-use forms during construction [RA 1.1] ▪ Reduced air pollutants since precast construction does not generate as much dust as cast-in-place construction [CR 1.2]
Prepare project environmental management plan (PEMP)	▪ Establishes a sustainability management system by identifying responsible parties for maintaining bridge during its operational life [LD 1.2] ▪ Fosters collaboration by obtaining multidisciplinary input on potential environmental impacts of project during planning phase [LD 1.3]
Integrated architectural and structural design	▪ Whole systems design results in a project that performs more efficiently [LD 1.3] ▪ Reduces embodied energy since integrated design results in savings in materials [RA 1.1]

© ASCE 2014

	▪ Enhances deconstruction, since concrete and steel components are separated in the optimized design [RA 1.7]
Recycled rice husk in bridge deck surface	▪ Achieves by-product synergy, since rice husks are a byproduct of human food processing [LD 2.1]
Perform life cycle analysis	▪ Life cycle analysis will identify contributions to carbon emissions and allows for design to be refined to reduce emissions, can be performed once design has been finalized [CR 1.1]
Switch from terracotta louvers to aluminum louvers	▪ Reduces heat island effect due to higher SRI of aluminum in contrast to terracotta [CR 2.5] ▪ Incorporates recycled materials, since aluminum is highly recyclable [RA 1.3]
Advocate for Envision certification rather than LEED certification	▪ Demonstrates leadership and commitment to advancing Envision as the appropriate rating system for infrastructure [LD 1.1]

The following table presents the percentage of "yes" responses captured by the Envision checklist. This highlights the categories with the most credits that would potentially be applicable to the design.

Table 3. Percentage of "yes" responses.

Category	Base Design	Optimized Design
Quality of Life	58%	69%
Leadership	37%	68%
Resource Allocation	12%	24%
Natural World	35%	35%
Climate and Risk	0%	36%

Between the two alternatives, the largest difference in scores occurs in the Climate and Risk category, with the base design scoring 0% and the optimized design scoring 36%. The second largest difference occurs in the Leadership category, with the base design scoring 37% and the optimized design scoring 68%. The third largest difference occurs in the Resource Allocation category, with the base design scoring 12% and the optimized design scoring 24%.

© ASCE 2014

Table 4. Percentage of "no" responses.

Category	Base Design	Optimized Design
Quality of Life	35%	23%
Leadership	58%	26%
Resource Allocation	61%	49%
Natural World	9%	9%
Climate and Risk	100%	64%

Table 5. Percentage of "not applicable" responses.

Category	Base Design	Optimized Design
Quality of Life	8%	8%
Leadership	5%	5%
Resource Allocation	27%	27%
Natural World	57%	57%
Climate and Risk	0%	0%

Part 2 – Embodied Energy. Table 6 summarizes the data used to estimate the embodied energy and carbon of the bridge. The values are sourced from Hammond and Jones (2008). The results of the embodied energy calculation are presented in Table 7 for the base design and Table 8 for the optimized design.

Table 6. Summary of energy data (Hammond & Jones, 2008)**.**

Embodied carbon	**$kgCO_2/kg$**
Concrete	0.13
Steel	1.77

Embodied energy	**MJ/kg**
Concrete	0.95
Steel	24.4

Table 7. Embodied Energy of Base Design.

Item	Qty. Concrete $[1x10^3$ kg]	Qty. Steel $[1x10^3$ kg]

© ASCE 2014

Substructure		
B1 to B8 Columns	320	35.8
B1 to B8 Bent Caps	440	16.5
Superstructure		
CIP Deck Section	740	41.1
Deck slab	593	33.1
Canopy Frame		
W16x36 Solid Beams	-	31.4
Total	2090	157.9
Embodied energy: MJ/m^2	1835.3	3559.9
Embodied carbon: $kgCO_2/m^2$	251.1	258.2
Total embodied energy: MJ/m^2	5395.1	
Total embodied carbon: $kgCO_2/m^2$	509.3	

Table 8. Embodied Energy of Optimized Design.

Item	**Qty. Concrete [1x10^3 kg]**	**Qty. Steel [1x10^3 kg]**
Substructure		
B1 to B6 Columns	240	26.8
Superstructure		
Hollow Rectangular Beam	515	28.8
Transverse Ribs	496	27.7
Deck slab	593	33.1
Canopy Frame		
W16x36 Castellated Beams	-	15.3
Total	1844	131.7
Embodied energy: MJ/m^2	1620	2970
Embodied carbon: $kgCO_2/m^2$	221.7	215.5
Total embodied energy: MJ/m^2	4590	
Total embodied carbon: $kgCO_2/m^2$	437.2	

The base design results in a total embodied energy per square meter of 5395 MJ and a total embodied carbon per square meter of 509 $kgCO_2$.

The optimized design results in a total embodied energy per square foot of 4590 MJ and a total embodied carbon per square meter of 437 $kgCO_2$.

© ASCE 2014

Comparing the base design to the optimized design leads to a 15% reduction in embodied energy and a 14% reduction in embodied carbon.

DISCUSSION OF RESULTS

Part 1 – Envision Checklist. The Envision Checklist shows a significant distinction between the base design and the optimized design in most categories. The Natural World category shows no change, since the optimized design did not improve on any of the credits due to existing constraints that could not be modified, such as the location of the site in an urban environment (thus eliminating many of the Natural World credits related to protecting habitats, farmland, etc.).

In Quality of Life, the optimized design improves on the base design by reducing the amount of noise and vibration during the construction process. Switching from primarily a cast-in-place design to a precast design reduces the need for cement trucks and mitigates dust during concrete mixing operations.

The checklist also captures improvements in the Resource Allocation category. The increased points in Resource Allocation come from providing an integrated structural and architectural design that ultimately leads to a reduction in material use. The optimized design fulfills the credit for performing an assessment of embodied energy. For a reduction of 15%, this would qualify for the "Enhanced" category.

Envision provides credits for using materials that are by-products of industrial processes or materials with recycled content. The proposed deck design will make use of rice husk flooring, which is derived from a by-product of human food processing. The team also explored the option of using sustainable concrete mixes that incorporate fly ash. The louvers that will make up the shading components of the cantilevered canopy were envisaged to be terracotta rods in the base design, but were changed to aluminum sections in the optimized design. Since aluminum is a highly recyclable material, this earns the project points under the materials use category.

In the Climate and Risk category, the optimized design provides the benefit of precast construction, which minimizes noise and dust generation on site. Prefabricating the bridge components prevents wasteful single use formwork and reduces the need for cement trucks, which would cause traffic congestion as well as noise and air pollution. All of these design decisions are recognized by Envision and rewarded accordingly under the Climate and Risk category.

In conclusion, the Envision checklist primarily focuses on high-level societal and systemic impacts. The changes that were implemented in the optimized design run the gamut of specific component-level changes such as reduced deck cross section to "big picture" decisions such as project location. Envision is better suited to capture

© ASCE 2014

the benefits of these high-level design choices rather than project-specific design choices.

Part 2 – Embodied Energy. From a strictly environmental standpoint, going from the base design to the optimized design results in a 14-15% reduction in embodied energy and carbon. These savings are due to the reduced quantity of concrete and steel required to construct the optimized design in contrast to the base design. Although the volumes of concrete are fairly similar, the optimized design requires significantly less steel than the base design due to changes in the cantilevered canopy.

In the optimized design, castellated steel beams are used to reduce the cross sectional area of the W16x36 beams in the canopy structural framing. These openings result in a more efficient use of the beam cross section. Additionally, the canopy in the optimized design no longer wraps below the soffit of the bridge, reducing the required volume of steel by one half. Since steel production is significantly more energy intensive than concrete production (Martin, 2003), the increased quantity of steel in the base design weighs heavily on the sustainability of the base design.

The reduction in concrete volume in the optimized design primarily comes from the removal of two columns, bringing the total number of supports from eight to six. The optimized design also obviates the need for bent caps, further reducing the required quantity of concrete. However, both of these changes come at the cost of the superstructure depth. Since the deck depth is proportional to the span length, which increases due to the removal of supports, some of the concrete saved is offset by an increased superstructure depth.

Comparing Envision and embodied energy. Major differences exist between the two methods discussed above. The Envision checklist is biased towards high level decisions related to the preliminary planning and site selection of the project. These questions are best answered before beginning the conceptual design of the project. Envision does not distinguish between detailed design and construction decisions that occur during alternatives analysis, such as choosing cast-in-place vs. precast construction. These choices can have a significant impact on the environmental cost of a project, e.g. lane closures for formwork erection leading to congestion, or emissions related to transport of precast sections from distant suppliers.

A key point to consider is that this research is based only on the Envision checklist, and not on the Envision workbook or other tools that have been provided by ISI. A more advanced evaluation of the project using the Envision workbook, or with future editions of the Envision rating system, may address calculations and documentation details to an extent that the checklist cannot provide, since it is meant to be a preliminary analysis tool.

© ASCE 2014

The embodied energy analysis also results in a biased view of a project's sustainability metrics. The analysis performed in this paper is concerned only with the total volume of materials, but further analysis needs to take into account the energy costs of transporting materials to site. The embodied energy results as presented here also neglect end-of-life recycling of material, which a full life cycle analysis would capture. Regardless of these shortcomings, embodied energy analysis will never be able to take into consideration societal factors like employing underrepresented groups or enhancing public space. It is instead a purely quantitative indicator of sustainable performance.

CONCLUSION

The Envision rating system has a different focus from what researchers in sustainable infrastructure are accustomed to seeing. Instead of a quantifiable analysis resulting in a defined amount of embodied energy or carbon, Envision evaluates a project much more subjectively. This holistic approach weighs societal factors more heavily than any energy study performed to date. The drawback to this is that a new paradigm such as Envision can only begin the conversation for the industry – the onus of work to develop and refine the system requires the collective effort of many. Owners and clients must push for Envision rather than LEED on their infrastructure projects in order for the system to progress. It is especially important that engineers and architects are brought on early in the process to fully implement integrated, holistic solutions in the final design. The ultimate goal for all is a system with balanced, sensible metrics that produce truly sustainable infrastructure projects.

REFERENCES

Collings, D. (2006). An Environmental Comparison of Bridge Forms. *Proceedings of the Institute of Civil Engineers*, 163-168.

Hammond, G. P., & Jones, C. I. (2008). Embodied energy and carbon in construction materials. *Proceedings of the Institute of Civil Engineers*, 87-98.

Long, A. E., Basheer, P., Taylor, S., Rankin, B., & Kirkpatrick, J. (2008). Sustainable Bridge Construction Through Innovative Advances. *Proceedings of the Institute of Civil Engineers*, 183-188.

Martin, A. J. (2003). Aspects of Concrete Bridges in Sustainable Development. *Concrete Bridges in Sustainable Development.* Dundee, Scotland.

Wong, A. (2011). *Embodied Carbon Life-Cycle Assessment of Bridges: A Case Study of a Sea Crossing in Hong Kong.* Hong Kong.

© ASCE 2014

Zhang, C. (2010). Delivering Sustainable Bridges to Help Tackle Climate Change. *Proceedings of the Institute of Civil Engineers*, 89-95.

© ASCE 2014

The Gerald Desmond Bridge Replacement Envision™: Using Key Project Innovations to Understand the Envision™ Framework

Josh Mattheis[1] P.E. ENV SP, Mike Iswalt[2] AICP PTP, Josue Enriquez[3] ENV SP and Joshua Bird[4] ENV SP

[1] M.S.C.E, B.S.C.E; Arup; 12777 West Jefferson Blvd Building D Los Angeles, CA 90066; PH (310) 578-4502; email: josh.mattheis@arup.com
[2]M.S.C.E, M.C.R.P; Arup; 560 Mission Street, Suite 700, San Francisco, CA 94105; PH (415) 946-0748; email: michael.iswalt@arup.com
[3] M.S.C.E, B.S.C.E; Arup; 12777 West Jefferson Blvd Building D Los Angeles, CA 90066; PH (310) 578-4421; email: josue.enriquez@arup.com
[4] MEng Civil and Structural Engineering; Arup; 12777 West Jefferson Blvd Building D Los Angeles, CA 90066; PH (310) 578-4559; email: joshua.bird@arup.com

ABSTRACT

The purpose of this paper is to use the Envision™ framework to evaluate a portion of the Gerald Desmond Bridge Replacement Project (GDBRP), located in the Port of Long Beach (POLB), in order to test the applicability of Envision™ framework to similar projects around the world. Evaluation will focus on a portion of the western approach to the main span, proposed in the project reference documents as an elevated horse-shoe ramp but modified through value engineering to an undercrossing, using roadway geometry referred to as the Port Access Undercrossing (PAUC). Acknowledging that many infrastructure owners already have their own sustainability guidelines, this paper also examines synergies between Envision™ and the Port of Long Beach's own sustainability framework, the Green Port Policy (GPP).

The Envision™ analysis confirms benefits across several different criteria introduced to the GDBRP by the application of the PAUC alternative. Comparison of the Envision™ analysis results to POLB objectives indicate that the Envision™ framework is well adapted to work within objectives of the POLB's GPP by providing tools to evaluate a wider range of assets.

INTRODUCTION

Sustainability is a key component of any large infrastructure project, but design builders often struggle to grasp what a sustainable project entails in solid terms. Envision™ provides the framework within which designers and contractors can work to design and construct a truly sustainable project, providing a holistic approach to sustainability that is all-too-often poorly applied on infrastructure projects.

© ASCE 2014

Located in the Port of Long Beach, California, GDBRP presents an ideal context to explore the potential of Envision™ when assessing the sustainability of infrastructure projects for several reasons:

- POLB is the second busiest container port in the United States, after the neighboring Port of Los Angeles, making the context relevant for other large Port projects.
- GDBRP is critical to the continued growth of the Port of Long Beach, establishing the bridge as a critical economic link.
- The contract procurement model is design and build, coherent with developing world-wide trends toward design and build.

Thus, GDBRP is relevant in terms of its physical context, economic significance and contract procurement type, all increasingly common aspects of large capital improvement projects around the world.

Envision™ Structure

Envision™ is a sustainability rating system establishing a holistic framework for evaluating and rating infrastructure projects against the needs and values of the community, not only during construction, but during the project's design life. It is intended to be applied to and adopted by the infrastructure industry, similar to how LEED has become an industry standard for green building projects.

The Envision™ system is comprised of four stages as noted in Figure 1. The first stage is aimed towards the conceptual phase of a project, while the second focuses on the detailed design and construction phases. Stages 3 and 4 are still under development by the Institute for Sustainable Infrastructure (ISI) and Zofnass Program for Sustainable Infrastructure.

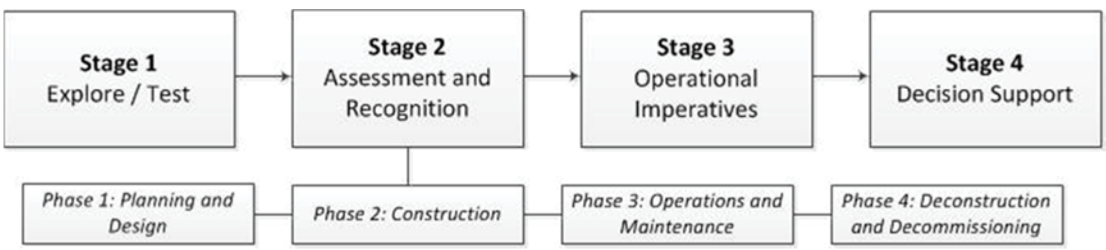


Figure 1. Structure of Envision™ Rating System

In order to evaluate a project, sixty credits are proposed, organized into five categories and fourteen subcategories:

- Quality of Life: Purpose, Community, Wellbeing
- Leadership: Collaboration, Management, Planning
- Resource Allocation: Materials, Energy, Water

© ASCE 2014

- Natural Work: Silting, Land and water, Biodiversity
- Climate and Risk: Emissions, Resilience

These categories are evaluated in Stage 1 and again in Stage 2, but with more detail. The Stage 1 evaluation is a high level assessment intended to rapidly compare project alternatives, facilitated with a checklist-style tool developed by ISI. During Stage 2, a more in-depth assessment is performed with justifications for each category, ultimately to be submitted to ISI for their scoring. Scores are proclaimed as either:

(1) Improved (2) Enhanced (3) Superior (4) Conserving (5) Restorative

This allows the project to be rated in a way which is quantifiable and measureable, rather than purely qualitative.

Gerald Desmond Bridge Replacement Project Background

As depicted in Figure 2, the Gerald Desmond Bridge Replacement Project features a network of approximately 6,000 feet of box girder approach structures leading up to a 2,000 foot long cable-stayed main span bridge with a 100-year design life. The new bridge is located immediately adjacent to the functionally deficient existing bridge, which will remain in service until the replacement bridge is opened. When finished, the replacement bridge will improve traffic flows across the bridge and increase vertical clearance to the shipping lane below, permitting the increasingly common Post-Panamax cargo ships to pass. Total project cost is currently assessed at approximately 1.2 billion dollars.

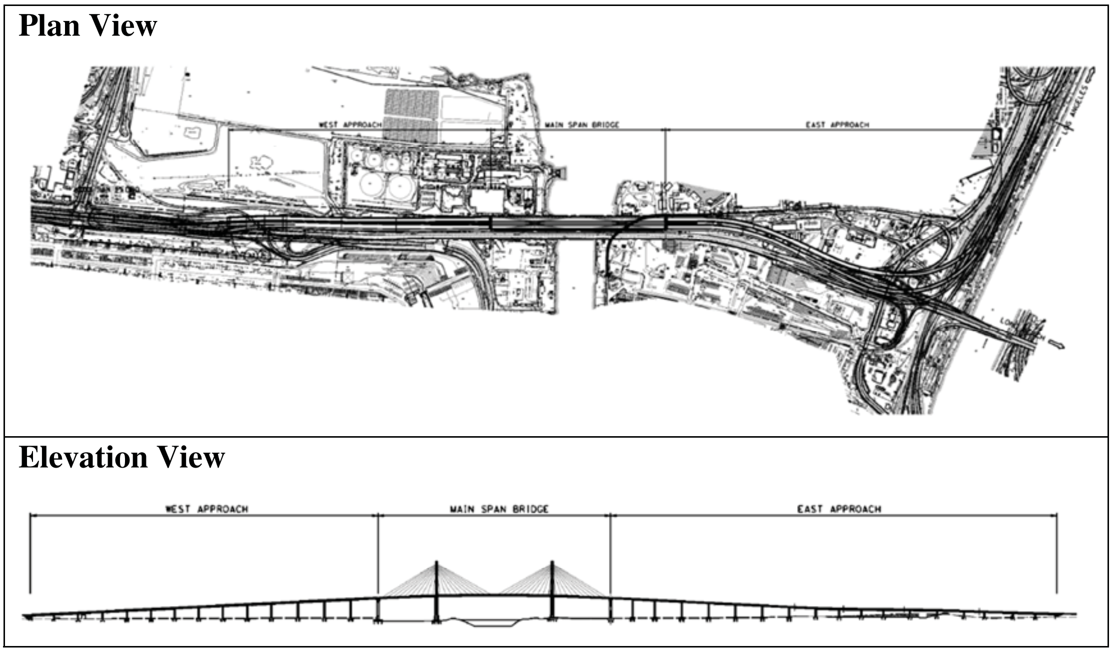


Figure 2. Gerald Desmond Replacement Project plan and elevation view.

© ASCE 2014

HORSESHOE vs. PAUC

As shown in Figure 3, the tender reference design (the reference design) features a vertically grade-separated "horseshoe" bridge structure at the western approach to the GDBRP providing access from the new westbound bridge to Pier T Avenue and from Pier T Avenue to the new eastbound bridge. At-grade ramp connections were provided between Pier T Avenue and Ocean Boulevard. The horseshoe ramps allow full access between Pier T Avenue and Ocean Boulevard.

The SFI Joint Venture (SFIJV) proposed to replace the horseshoe ramps in the reference design with two protected PAUC U-turn lanes east of State Route 47 (Terminal Island Freeway). Vehicles traveling westbound Ocean Boulevard towards the main Totals Terminal International (TTI) entrance would then use one of the dedicated free flow U-turn lanes to cross under Interstate-710 instead of the horseshoe ramps included in the reference design. Vehicles leaving the main TTI exit and travelling east towards Ocean Boulevard would cross under Interstate-710 via a newly constructed local access road and use the second dedicated free-flow U-turn lane to access eastbound Interstate-710.

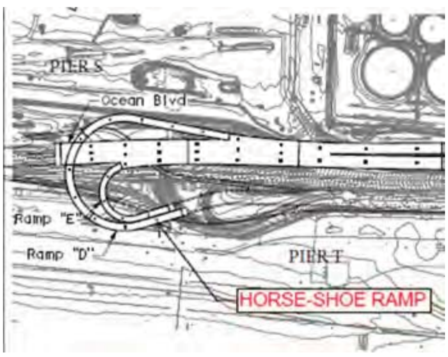
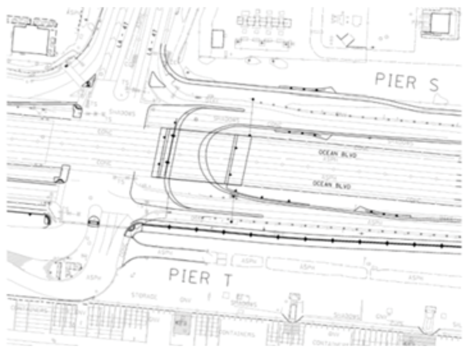
Horse-Shoe Ramp	PAUC
	

Figure 3. Horse-Shoe Ramp vs. PAUC Design.

At the westbound Ocean Boulevard / State Route 47 intersection, the left-turn lane is eliminated and replaced with a shared left/through lane. The eastbound travel lanes at the eastbound Ocean Boulevard / State Route 47 intersection are realigned slightly to the south to line up with the receiving lanes on the other side of the intersection. No changes to the lane configuration are proposed. These changes do not adversely affect the Level of Service (LOS) compared to the reference design.

The application of this roadway geometry on a California Department of Transportation (Caltrans) roadway network is unique in context, but the change was accepted by the Port of Long Beach based on the many advantages it brings across

© ASCE 2014

several categories. As well as being innovative, the PAUC provides an ideal context for comparison with the reference design using the Envision™ framework.

METHODOLOGY

Envision™ analysis is carried out within the confines of a Stage One analysis, augmented with detailed fact-finding and assessments where possible. This approach reflects the actual status of the project at the time of this analysis, being that the detailed design is only partially complete. A full Stage Two analysis is not yet feasible, but enough information exists to exceed what would typically be a high level Stage One analysis.

As depicted in Figure 4, a high level assessment of the entire GDBRP is performed using the Envision™ Self-Assessment checklist first with the reference design layout, and again with the PAUC. In this way credits relevant to the comparison are identified by their divergent values between the reference design and the PAUC design. These credits are isolated, and examined with a more detailed collection of information. An accurate picture of the differences between the two options within the Envision™ framework is thus developed without dwelling on the aspects which are not impacted by the introduction of the PAUC.

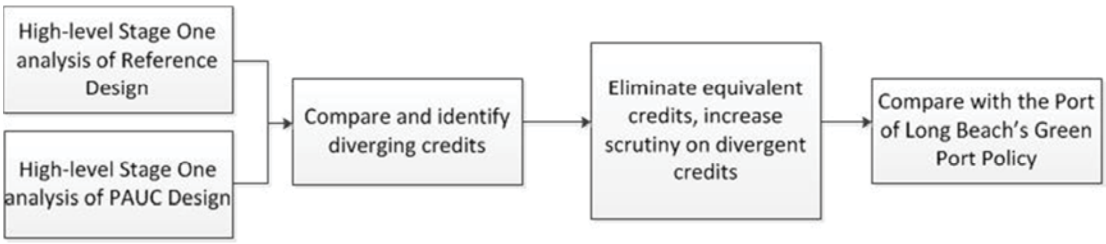


Figure 4. Analysis of methodology.

Following the above exercise, use of the Envision™ framework in conjunction with the Port of Long Beach's Green Port Policy is considered as a discussion.

Identification of Stakeholders

The Envision™ framework places heavy emphasis on quality of life, community, well-being, collaboration, and planning, all of which require an accurate assessment of the local stakeholders. There are numerous stakeholders project-wide, but in the context of this assessment, a shortlist of stakeholders directly impacted by the Horseshoe ramp / PAUC alternative is used as listed below:

- Port of Long Beach
- Port of Los Angeles
- City of Long Beach

- Caltrans
- Totals Terminal International (TTI)
- Commuters from San Pedro south bay to Long Beach

Envision™ Assessment of PAUC vs. Horse Shoe

Figure 5 summarizes the results from the Envision™ Self-Assessment Checklist after performing a high level Stage-One analysis for both the PAUC and Horse Shoe reference design. The "Percent Credits Achievable" chart highlights the percentage of credits, listed in the Envision™ checklist, applicable for each sustainability category. Conversely, the "Percent Credits Not Achievable" chart shows the percentage of credits that cannot be achieved. The self-assessment checklist provides a quick and quantifiable comparison between the PAUC and Horse-Shoe reference design, in terms of sustainability, as defined by Envision™. Although the percentages shown in the table do not reflect a definite level of sustainability performance, it does hint at which alternative will perform higher in a Stage-Two Envision™ analysis.

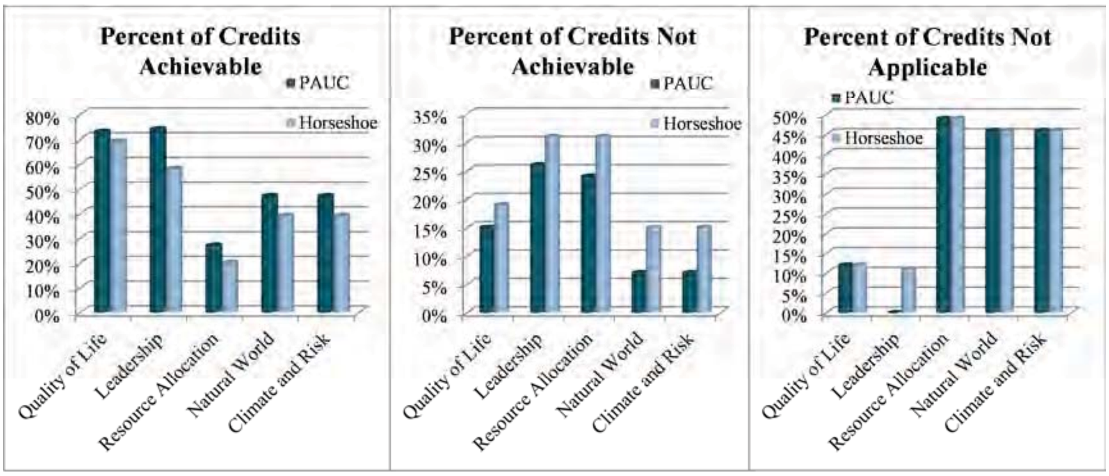


Figure 5. Envision™ Self-Assessment Checklist Results.

The Envision™ self-assessment checklist indicates a preferential trend for the PAUC in all five sustainability categories.

Compared to the Horse-Shoe reference design, the PAUC improves the community's quality of life by reducing the amount of bridge construction and associated noise and vibrations. However, we note that when evaluating credit QL 2.2 Minimize Noise and Vibration, both the reference design and the PAUC reflected the same "Yes" assessment even though the PAUC presents clear advantages in terms of this criterion. This underlines a risk of a rapidly performed Stage 1 analysis.

The largest difference between the PAUC and the reference design is in the Leadership category. By proposing the PAUC option, the project team championed a

© ASCE 2014

non-standard solution never before adopted in the state of California, providing benefits to several stakeholders. Envision™ acknowledges the leadership required to make new ideas such as the PAUC a reality through credits such as LD3.2 - Address Conflicting Regulations and Policies. This pursuit accounts for the 16% difference in the Leadership category between the PAUC and the reference design.

Modest improvements are also noticeable for the Natural World and Climate and Risk categories with a difference of 8%. The variance is attributed to the following factors:

- The PAUC avoids excavating into a benzene plume (NW1.4 Avoid Adverse Geology).
- The PAUC reduces the percentage of Low Solar Reflectance Index by limiting the amount of asphalt required (CR2.5 Manage Heat Island Effects).

The removal of the Horseshoe ramps significantly reduces the net embodied energy (RA1.1 Reduce Net Embodied Energy) of the project which accounts for the 7% difference under the Resource Allocation category.

Table 1. Embodied Energy and Carbon Conversion Values

Item	Concrete	Steel
Embodied Energy [MJ/kg]:	0.950	24.4
Embodied Carbon [kgCO_2/kg]:	0.130	1.77

Using the rates described in Table 1, Table 2 summarizes the Net Embodied Energy savings obtained by replacing the Horse-Shoe ramps with the PAUC design, using approximate steel reinforcement quantities per cubic meter of concrete as identified by Caltrans (2005).

Table 2. Embodied Energy and Carbon

Item	Horseshoe Ramps	PAUC	Savings
Embodied Energy [MJ x 10^6]:	80.0	11.2	**68.8**
Embodied Carbon [kgCO_2 x 10^6]:	8.06	1.07	**6.99**

According to the Environmental Protection Agency (EPA), the embodied energy saved by selecting the PAUC over the Horseshoe ramps is the equivalent of 1,483,000 gallons of gasoline consumed. Similarly, the combined savings of carbon dioxide is the equivalent of 780,000 gallons of gasoline consumed (EPA, 2014).

© ASCE 2014

Synergy with POLB Green Port Policy

The POLB has long been considered a leader in sustainable port practices ("Greening of California 2006" Award) and as such has implemented a Green Port Policy (GPP). While Envision™ is an assessment framework rather than a policy, significant parallels can be drawn between it and the Port of Long Beach GPP.

In its GPP, the POLB has developed a 'decision-making framework' (Port of Long Beach, 2014) to mitigate the negative impacts associated with port operations. Evolving from the POLB previous 'Healthy Harbors Program' the GPP was adopted in 2005 with fundamental goals associated with 'Air, Water, Wildlife, Soil/Sediment, Sustainability, and Community Engagement'. While Envision™ is an excellent tool, general enough to be applicable to the full spectrum of infrastructure projects, the GPP is clearly and unsurprisingly, specific to the operations of a port.

Though metrics exist within the GPP, some principles such as water and wildlife is less measurable. In these categories, pairing the GPP with Envision™ could prove beneficial. There is scope to further investigate the correlation between Envision™ and GPP which could be mutually beneficial to stakeholders, adding value to the GPP and promoting the use of Envision™ on major infrastructure projects. Both documents should be viewed as complimenting each other, and playing different roles, to be applied to a project in tandem, rather than as an either-or.

Whilst there are targets within the GPP for attaining LEED accreditation for new buildings, there is currently no similar target for the upgrades to infrastructure. Perhaps that is because until now, there was no infrastructure equivalent to LEED. Envision™ could compliment the GPP in a manner similar to how LEED has for its building projects.

CONCLUSION

The Envision™ framework provided a versatile and effective toolset to evaluate GDBRP reference design and PAUC scenarios, and ultimately confirmed that the PAUC is the preferable configuration. The organization of target credits into categories and category sub-sets is an effective way to rationalize a large and variable set of data. By providing ready-made tools such as the Envision™ Self-Assessment checklist, ISI has enabled teams such as SFIJV and the Port of Long Beach to roll out an efficient and consistent basis of comparison.

The disadvantages of the Envision™ framework are related to its universal nature, particularly in the Stage One analysis where this study is largely based. In order to be applicable to a wide range of situations, credit evaluations tend to be open to interpretation to the point where some potentially key project aspects may not be accurately reflected in the evaluation. As an example, in evaluating credit QL 2.2

© ASCE 2014

Minimize Noise and Vibration, both the reference design and the PAUC reflected the same "Yes" assessment, even though the PAUC presents clear advantages in terms of this criterion. To mitigate this tendency, we recommend using the same hybrid approach as was followed for this research in which partial justification is required for each Stage One analysis credit to avoid stepping over important conclusions.

Envision™'s emphasis on the quality of life, community, well-being, collaboration, and planning are innovative and encourage forward-thinking project developments such as the PAUC. In particular, strong results in the Leadership category contributed to the favorable rating of the PAUC within this research. In parallel, the PAUC is a refinement that has brought many advantages to POLB, the project owner, demonstrating that the Quality of Life and Leadership aspects of the Envision™ rating system can be successful in promoting solutions which benefit all stakeholders, including owners.

The Port of Long Beach's Green Port Policy is well complimented, but not replaced by the Envision™ rating system. The GPP is a policy specific to the Port and as such brings metrics not specifically contained within the Envision™ Framework. Together, both systems could result in an approach that will complement the already impressive dedication of the Port of Long Beach's environmentally focused decision making by introducing a toolset adapted to a wider range of infrastructure elements.

References

Caltrans (2005). *Bridge Design Aids Section 11 - Estimating*. Retrieved Feb 24, 2014, from http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/bridge-design-aids/bda.html.

Environmental Protection Agency. Greenhouse Gas Equivalencies Calculator. Retrieved Feb 24, 2014, from http://www.epa.gov/cleanenergy/energy-resources/calculator.html

Institute for Sustainable Infrastructure and the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design (2012) Envision™: A Rating System for Sustainable Infrastructure. Washington, DC, Institute for Sustainable Infrastructure.

Port of Long Beach. 2014. *Port Received "Greening of California" Environmental Award*. [press release] 10/12/2006.

Port of Long Beach. 2005. Long Beach Harbor Department Green Port Policy – "White Paper'. Retrieved Feb 20, 2014, from http://polb.com/

Zhang, C. (2010). Delivering Sustainable Bridges to Help Tackle Climate Change. *Proceedings of the Institute of Civil Engineers*, 89-95

© ASCE 2014

A Value Based Rating System for Envision ™

Christopher Behr[1]
HDR Engineering, Decision Economics
8403 Colesville Rd., Suite 910, Silver Spring, MD 20910
PM (240) 485-2617; email: cbehr@hdrinc.com

Abstract

Institute for Sustainable Infrastructure (ISI) developed the *Envision*™ rating system in collaboration with the Zofnass Program for Sustainable Infrastructure at the Graduate School of Design, Harvard University, to promote the integration of sustainability goals into infrastructure planning and design. This paper develops a concept for incorporating economic valuation measures with *Envision*™ to further its growing use among infrastructure owners in making plans and designs more sustainable. Integration of economic valuation with *Envision*™ begins with recognition that both approaches measure some of the same dimensions of projects. Economic valuation would support the *Envision*™ credit and point system by providing evidence and analytical rigor on how people value economic, environmental, and social outcomes. Economic valuation can help make the *business case* for owners to use *Envision*™ to choose projects that provide higher sustainability value in ways that are directly comparable to project costs. A number of challenges and opportunities of integrating economics and *Envision*™ are discussed and final comments include a proposed path forward for the rating system as it evolves.

Introduction

Deciding among infrastructure alignments, technologies, designs, and other relevant features is rarely straightforward. Public officials hear from stakeholders representing all sides and levels of influence and often need justification for the course of action taken. While cost control is a key driver, it is not the only objective; increasingly, sustainability goals are included as part of the decision criteria. Standardized approaches to support decision making already exist and include formal environmental impact assessments, financial feasibility analyses, capital project scoring systems, and economic benefit-cost analyses. These analyses, while they differ in nature and scope, all evaluate a wide range of project impacts for screening and prioritizing purposes. While environmental impact assessments are generally mandated for major capital projects, other financial, economic and project scoring analyses often remain as internal decision tools.

Sustainability-oriented rating systems (e.g. Envision™, BE^{2}ST-In-Highways™, Greenroads™, INVEST, and GreenLITES) supplement existing

[1] Special thanks to Stéphane Gros (HDR) and Peter Binney (Merrick), for their thoughts on strengthening earlier drafts.

© ASCE 2014

analyses and reorient decisions towards new goals. That is, while existing environmental impact analyses largely help identify what *not* to do, rating systems create incentives to extend beyond cost and impact minimizing options. Rating systems, through the credit scoring framework, establish standards of excellence about just what is *sustainability*, or at least, what are *more sustainable investments*. Planning and design decisions that generate higher points from combinations of credits are then recognized by having achieved a certain status (e.g. bronze, silver, gold or platinum). Ultimately, when a rating system is broadly recognized in the market or among peers, the *status* of a project as being among the best can drive an owner to make investments as steps to sustainability.

Envision™ is a comprehensive sustainability rating system that aims to establish best practices for public infrastructure and throughout the implementation process. It includes credits related to site selection, resource use and management, and stakeholder engagement during stages of infrastructure planning, design and operations. While this rating system is in its early stages of development, it stands apart from others because of the backing of major engineering and infrastructure industry leaders and its collaboration with the Zofnass Program at Harvard University.

Recent discussions on *Envision*™ have explored issues in integrating economic analysis with the rating system to help make a *business case* for using *Envision*™ to choose projects that achieve sustainability goals, especially relative to project costs.[2] It is argued here that by utilizing the best available economic evidence and analytical rigor on how people truly value economic, environmental, and social outcomes, the inherent incentives in the rating system for better design and planning would possess a greater credibility for decision makers. However, it has thus far remained unclear what that integration with economics would look like. How would the *Envision*™ system be modified? What types of system performance data would be needed? What types of projects could this be applied to?

The integration of economics evidence with rating systems has a compelling rationale for any rating system. In this paper, the rationale is discussed using the *Envision*™ rating system as an example. Both the over-riding rationale for integration and several practical perspectives on how to integrate are presented. The paper includes a review of individual credits, available performance and monetary measures and outlines a phased process that ISI could draw from in subsequent updates of *Envision*™.

Principles of Economic Evaluation of Infrastructure

Economic analysis, especially benefit-cost analysis (BCA), is commonly used to support decisions on what and when to build some type of infrastructure. BCAs determine a project's net benefits in a systematic and theoretically-based process that

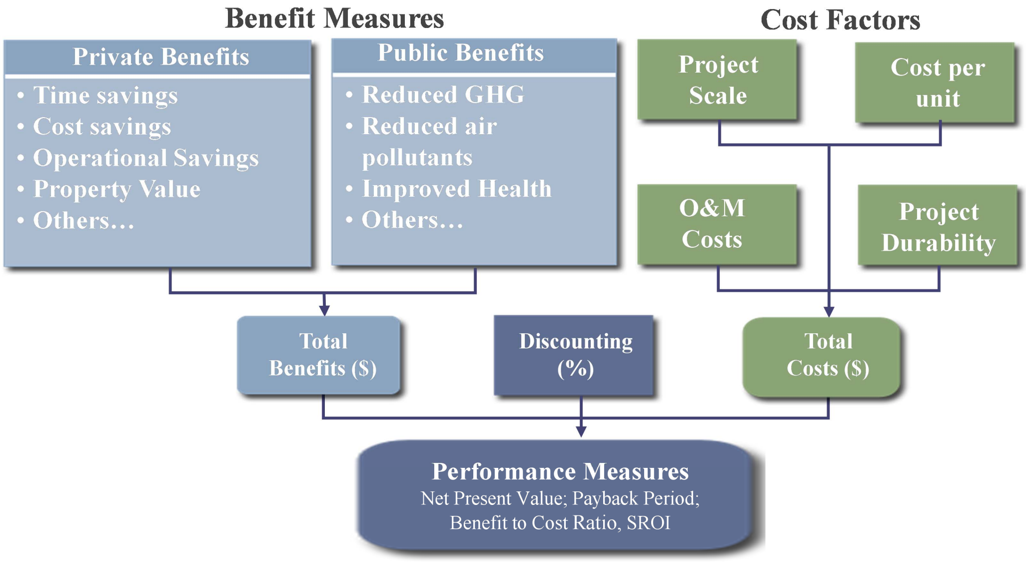
---

[2] This review of the *Envision*™ system has been undertaken as part of an ISI Task Force to consider how economic analysis can contribute to the effectiveness of the rating system in influencing infrastructure planning and design.

© ASCE 2014

attempts to comprehensively measure key differences in "build" and "no build" conditions. BCA metrics, including a benefit-cost ratio or net present value, typically include economic, environmental and social outcomes to the extent that they can be converted to monetary values (see **Figure 1**). Depending on the availability of site-specific data, a project's environmental impacts (e.g. change in environmental emissions) or social impacts (e.g. improved livability) can often be converted into dollar terms to be accounted for in quantitative ways.

Figure 1: Sample Schematic Diagram of Benefit and Cost Comparison



Economic value of projects with sustainability-related goals is often framed around a triple bottom line (TBL) (i.e. benefits associated with economic, environmental and social outcomes).[3] Of course, projects themselves only achieve incremental steps towards long-range sustainability goals. But, while the scale of impacts of any one project is small compared to broad sustainability targets, projects can be compared among feasible alternatives using a TBL framework. Economic analysis would reveal an alternative's comparative value in terms of each TBL benefit sub-total as well as a grand total.

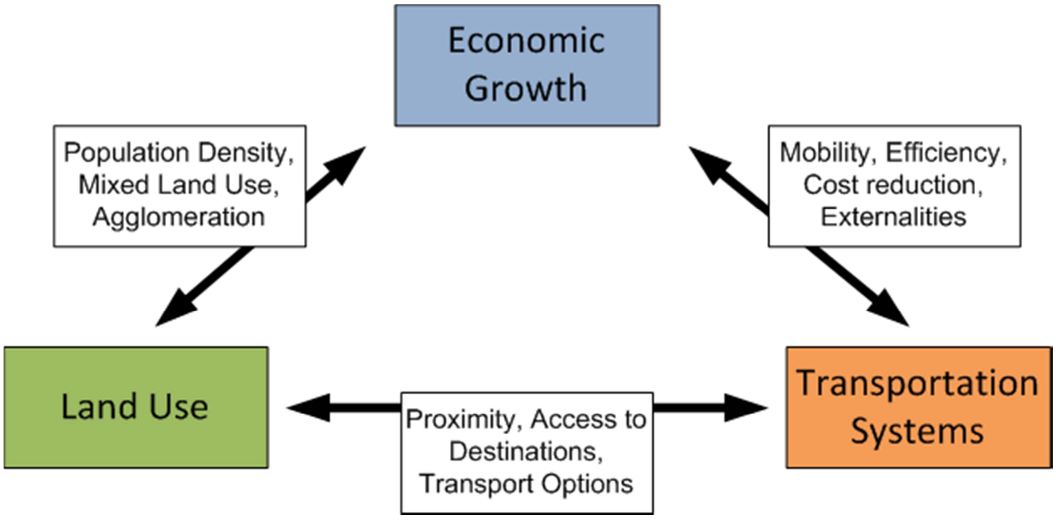
Arguably, the importance of applying economic principles and methods to assess a project's sustainability value is greater when *broader* impacts of infrastructure are observable or anticipated over some period of time and geographic scale. These benefits extend beyond the direct value of using infrastructure to include its influence on changing the demand for land uses. For example, a transportation system generates value through time and out-of-pocket cost savings, congestion relief, safety and other factors. However, transportation systems differ in how they influence land use, community character, and economic productivity (see **Figure 2**). Highways enable urban boundaries to expand which can increase property values in places made more accessible but also increase driving costs and public costs to provide services in outlying areas. Transit systems, in contrast, can concentrate

[3] For example, HDR's Sustainable Return on Investment (SROI) process has been broadly applied by the private and public sectors to understand the economic value of sustainability initiatives.

© ASCE 2014

growth in neighborhoods by making more efficient use of land and the transportation system. By bringing people and businesses closer together, these systems can lead to community revitalization.

Figure 2: Interaction of Infrastructure and Economic Development



The measure of sustainability, in such cases, is broader than the direct use of infrastructure and can include indirect and potentially overlapping influences. Achievement of sustainability goals are sometimes assessed through an ad hoc criteria-based scoring system. However, because of the theoretical foundation of economic analysis in handling multiple and integrated benefits of infrastructure, it provides a sound and consistent approach to estimating measuring a project's sustainability value.

Key Features of Effective Sustainability Rating Systems

Sustainability rating systems like *Envision*™ succeed by providing effective incentives for owners to improve project plans and designs towards higher achievement levels. The credits and points are structured to guide evaluation of options beyond the typical accounting of lifecycle costs and long-term financial returns. Core financial drivers are still relevant, but the credits and points provide a mechanism to account for the impacts of infrastructure to local communities and the environment. Thus, while owners typically seek a cost-effective design that can achieve goals for a minimum cost, sustainability rating systems aim to provide effective guidance toward achieving economic, social and environmental objectives within budget constraints. The rating system provides then a rationale about why agencies can benefit from investments that achieve a higher level of performance in meeting long term sustainability goals.

Most directly, rating systems provide feedback on the achievement of rating system goals, which in this case are more sustainable practices and outcomes. Rating systems gain legitimacy through transparency and consistency, as expressed through the system of categories and points that communicate, in effect, the standards of

© ASCE 2014

performance as expressed by the rating system designer. Guidelines are established for structuring a process to determine performance with credits and points whereby the rating system informs users of what it takes to "do better".

In conventional rating systems, a critical stage is the development of points per credit. In some cases, credits may have different levels of achievement that would be marked by different levels of performance. But, whatever the assemblage and description of credits, the development of points relies on either an explicitly or implicitly-developed weighting and scoring system. Weights are numerical values that typically add to 100% and are assigned to each type of credit relative to their importance to the rating system designer. Scores then may be established for increasing levels of achievement in each credit. Points would then be derived from a series of calculations between weights and scores.

Weaknesses though in rating systems can compromise their legitimacy and use. For example, if points are inconsistent and subjectively assigned to performance categories, they will not provide clear signals to users. Points can also inadvertently over-emphasize some performance goals. Consider an example of a rating system that provided for both renewable energy development (say, per kWh) and greenhouse gas emissions (GHG) savings (in tons). If an owner installs a new wind turbine on site, or alternatively chooses to buy renewable energy off the grid, the owner could gain points in both categories for achieving largely the same ultimate goal – greenhouse gas emissions savings. If both categories of points were intended to reduce GHG, these combined points would over-emphasize GHG reduction. Of course, if the goal directly entails market development for renewable energy, then these points should be appropriately scaled for market development only, not direct GHG reduction achievement. Such points should draw from an understanding of the energy sector.

Accordingly, it is important for a rating system to build on evidence of current 'baseline' standards of performance for various forms of infrastructure (e.g. ASHRAE standards for buildings). Points can be explicitly established for going beyond regulatory or conventional industry standards. It is also important to ensure that credits are distinct and do not include overlapping impacts with each other, or at least if they are, that the points are clearly distinguished to avoid double counting.

But, what difference can a rating system make in creating an incentive to plan, design or build more sustainable infrastructure? For example, (recalling **Figure 2**) how would the rating system handle two different types of transportation projects that are both designed well but yield different implications for the growth in a city? Would a value-based rating system provide a clear distinction?

Development of a Value-Based Sustainability Rating System

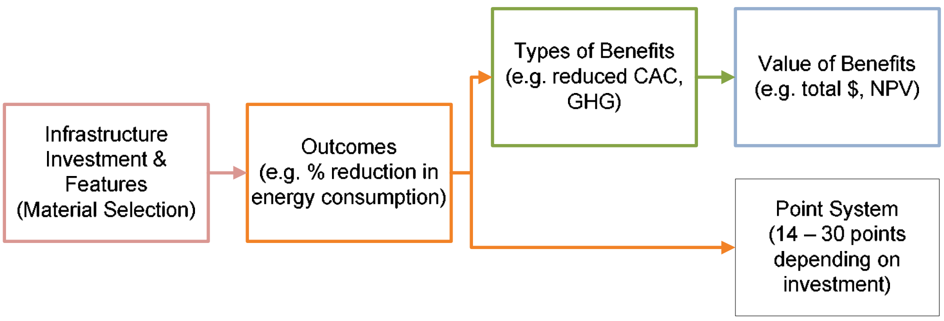
A rating system would be *value-based* if points are scaled to measurable and distinct impacts using principles of economic valuation. These principles include (a) measurement of performance relative to a baseline; (b) objective measures of valuation based on revealed and stated interests of the public; (c) independent and distinct measures of value (i.e. no double-counting); and (d) use of standard monetary units for comparison with costs.

© ASCE 2014

With *Envision*™, economic evidence and methods could be applied to many credits associated with infrastructure characteristics such as material or resource choice, site selection, designs, location choice, construction methods and balance between capital and operating costs. In some cases, additional assumptions would be required on standards of performance or status quo conditions, but reasonable assumptions can be determined based on the applicability of a credit to a location or infrastructure type. The rating system could then more completely measure infrastructure impacts that are excluded from financial and cost accounting measures, and do so in ways that are consistent with economic theory and evidence.

Alignment of economic valuation and points begins with recognizing that rating systems are analogous to a value-for-money proposition. Rating system credits represent different benefit categories and points per credit reflect the value of some improvement in process or outcome that incentivizes better practices. A credit system recognizes better designs and choices with higher points, and considering the cost of achieving points, this comparison is much like public benefit-cost ratio. Consider these parallels in **Figure 3** in which infrastructure investments to increase efficiency lead to reduced energy demand. In turn, there would be a corresponding reduction in electricity generation and emissions. Economic analysis translates reduced energy load into corresponding reductions in specific pollutants (based on the types of energy generators in that part of the grid) and then converts these reduced units of pollutants into total dollar values. A conventional credit and point system would assign points to a specific outcome, based on a weighting and scoring system.

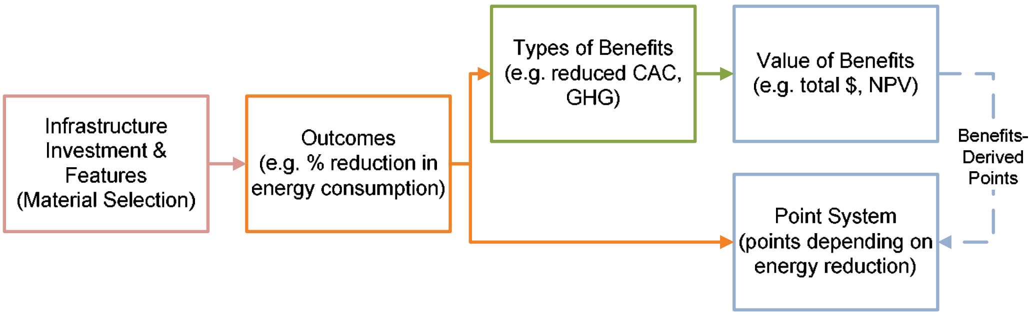
Figure 3: Alignment in Economic Analysis and Rating System Points



A value-based rating system though would identify all cases where such parallel measures of point and economic value occur and adjust points accordingly. **Figure 4** presents the same example as in **Figure 3** but illustrates that economic value would be used to adjust point levels. In some cases, such as air pollutant emissions, the economic value can be directly associated with the percentage reduction in tons of pollutant emissions from a baseline performance standard. From similar comparisons for each credit where value can be reasonably determined, a value per point can be estimated from a comparison of total value and total points for each achievement level (i.e. platinum, gold, etc.).

© ASCE 2014

Figure 4: Integration of Economic Value and Rating System Points



Conceptually, the number of points earned in a value-based scoring system would be similar to the total benefits estimated in a BCA for a given design. While assessments of points per cost can be analogous to BCA results, it is important to note that a rating system would not replace a BCA for project justification. However, by drawing from objective evidence on valuation, an effective rating system can better reflect the public's interest in economic, environmental and social benefits.

Stages in a Process to Align Economic Value and the *Envision*™ rating system

One approach for integrating the *Envision*™ rating system with economic principles and evidence could entail a series of steps that establish indicators of performance, and valuation metrics associated with this performance. Based on this refinement of credits and definitions, dollar values could be developed for different levels of achievement through *Envision*™. A third stage would compute implicit dollar values and link them to performance levels. The analysis would reveal the additional value achieved in points per credit (if applicable). Ultimately, these point-value links would be developed specifically for different sectors / industries and contexts depending on the applicability of credits to a project. It is anticipated that infrastructure in the following sectors could be evaluated: transportation (e.g. highway/bridges, transit, rail, airports and seaports), water (supply, drinking water treatment, wastewater, stormwater), and buildings (public service, residential commercial). A description of each phase is listed below:

1. **Parallel Economic Value Metrics:** In this phase, effort would be undertaken to estimate monetizable outcomes with respect to the existing rating system as a parallel measure of performance. This effort would establish quantitative measures of performance, with and without investment conditions. The effort would produce a framework to link credits to outcomes by identifying performance metrics per credit & points, associating benefit categories with performance metrics, grouping similar credits and identifying credits that relate to long-term value. The economic parameters would be applied to determine valuation metrics for each of the credits (as benefit categories) and to estimate total benefits from project. In addition, this analysis could estimate net benefits if costs can be associated with outcomes
2. **Refine Points to Emphasize Goals:** Building on the research in the first phase for establishing monetary value of credits, the point system could be refined to

© ASCE 2014

assess a range of benefits-to-points ratios for specific types of benefits (e.g. CAC, GHG) and overall benefits. This process would establish standard benefits-to-points ratio by benefit category. Points then could be refined to incentivize investments by rank credits with highest monetary values, re-weight and re-scale points per credit and establish points on credits without monetary value. This process in turn creates more flexibility to determine how points create incentives to perhaps move beyond a cost-minimization per point approach for owners, but a truly higher value per point.

3. **Regional and Sector-Specific Models:** Improved alignment between points and economic value can be achieved by aligning the point development to sector-specific goals and regional differences. So far the discussion in this paper has assumed that achievement levels in each project (across all different types) would achieve a performance level relative to a status quo. In this phase, separate point systems would be developed as a standard for each type of infrastructure (e.g. water supply, transit, energy source development). As an additional step, the point systems could account for differences in regional impact. For example, water pollution in different forms has greater or lesser impacts in different parts of the country. Estimates of site-specific impacts (e.g. livability) could also be derived.
4. **Integrated Infrastructure Model:** A final step could entail the development of a special composite rating system that addresses the integrated nature of urban-scale planning. Currently, many cities have created sustainability indicators but few of them are systematically organized. An urban-focused *Envision*™ system would account for the ways in which transportation, water, energy, and land use can be jointly planned to encourage sustainable and equitable development. Points systems would incentivize such cross-cutting coordination. Point values could draw from economic valuation research that links urban economic development and land use to MSA-level income growth and distributional goals.

Initial Assessment of Credits

An initial step has been taken below towards the development of a value-based-rating system for *Envision*™. Results of this review are presented in **Table 1**, in which for each credit that is applicable, a proposed standard of measure and value of impact are listed. In addition, two columns to the right indicates (1) whether data is readily available to measure and value impacts; and (2) whether that credit could be overlapping with another. Certainly, the existing descriptions of credits have provided information on quantitative measures of performance, but not in all cases. Ultimately, each measure of performance was defined so that a simplified economic value could be estimated.

The results indicate that credits are at different stages in readiness for economic value integration. Many credits are defined with quantitative measures already and can be readily monetized (e.g. GHG reduction). In other cases, some additional specification for measurement is required (e.g. water contamination). Still other credits appear to have overlapping impacts and their descriptions and scope of the credit may need to be refined or combined with another credit. In the case of

© ASCE 2014

Quality of Life credit (*QL1.1 Improve Community Quality of Life*), economic valuation can be applied only after the credit is better defined and possibly separated into various dimensions on the quality of life. Finally, many of the credits in the Leadership category lack direct valuation evidence and are process-oriented. While these credits are indeed valuable, consideration may be given to requiring them as prerequisites for points. In all cases, where economic evidence is lacking, more subjective indicators of value would have to be assigned. But, with economic values on other factors, these subjective indicators would be evaluated relative to objective evidence.

Concluding Remarks

This paper has developed a rationale and framework for integrating economic value and sustainable rating system – using the *Envision*™ as an example. Linkages are drawn initially between these two measurement systems. For example, economic valuation methods estimate a project's value from analysis of discrete, non-overlapping changes in various benefit categories. Quite analogously, rating systems are composed of credits and points per credit, which are added together to determine an overall qualitative level of achievement towards the rating system goals.

A value-based *Envision*™ system would set a new standard for rating systems by incorporating the best available information on how people value community and environmental resources. Arguably, the integration between economic evidence and rating systems would provide greater credibility to the point system because the value-based points would reflect the evidence of the value that the public places on triple bottom line outcomes. In contrast, subjective determination of points may lack consistency in reflecting how people, directly or indirectly, value alternatives for any new development. For example, if a benefit-cost analysis were conducted in parallel with the rating system, a ranking of projects may differ between the rating system and the economic analysis.

Finally, it is noted that some rating system are intentionally developed to incentivize project developers to *go beyond* a typical decision criteria even if the decision already accounts for financial, environmental, and societal outcomes – even through economic value standards. However, by developing a point system that initially integrates the evidence on how people value these outcomes, a more refined subjectively-based rating could better target the types of investments and outcomes that could achieve more sustainability-oriented results.

© ASCE 2014

Table 1: Proposed Framework for Measurement Units and Valuation Metrics for Envision Credits

ID	Description	Units	Value	Data	Rel.
Natural World					
NW1.1	Habitat Preservation	Acres of un-fragmented habitat	$ / acre ecosystem services	O	✓
NW1.2	Wetlands / Surface Water	Acres of wetlands avoided	$ / acre ecosystem services	O	✓
NW1.3	Farmland Preservation	Acres of lost farmland avoided	$ / acre	S	✓
NW1.4	Adverse Geology	Acres of adverse areas avoided	$ / acre ecosystem services	S	
NW1.5	Floodplain Avoidance	# properties impacted	$ / per property loss	S	
NW1.6	Avoid Steep Slopes	Avoided risk of mud slide / acre	$ / acre of damage	S	
NW1.7	Preserve Greenfields	Acres of brownfield dev't	$ / acre of value creation	S	✓
NW2.1	Stormwater Management	Acre-feet of water detained	Value of reduced water quality impacts	S	✓
NW2.2	Pesticide / Fertilizer Impacts	Reduced tons of pollutant runoff	Cost per ton of chemical contamination	L	✓
NW2.3	Surface / Groundwater Contam.	Acre-feet of contaminated water	Cost per ton of additional contamination	S	✓
NW3.1	Biodiversity	Acres of habitat loss	Included in NW 1.1		
NW3.2	Invasive Species Control	Reduced yields / acre (covered above)	Value /acre of production	S	✓
NW3.3	Disturbed Soil Restoration	Tons of soil restored	Value / Ton (Hauling, embodied energy)	S	✓
NW3.4	Wetland / Surface Water Functions	Acres of wetlands (average quality)	Value of improved ecosystem services	O	✓
Resource Allocation					
RA1.1	Embodied Energy	Total GHG in material	Value of GHG reduction	O	✓
RA1.2	Sustainable Procure.	Presence / absence of program	Value of reduced resource use	L	
RA1.3	Recycled Materials	Tons of recycled materials	Value / Ton (Trucking, energy)	O	✓
RA1.4	Regional Materials	Tons of local material	Value / Ton (Trucking, energy)	O	✓
RA1.5	Landfill Waste Diversion	Cubic yards of landfill space	Value / CY (Shadow price)	S	✓
RA1.6	Reuse Excavated Materials	Tons of reused excavated material	Value / Ton (Trucking, energy)	O	
RA1.7	Deconstruction/Recycling	Tons of (future) recycled materials	Value / Ton (Trucking, energy)	L	✓
RA2.1	Energy Efficiency/Conserv.	kWh reduced (regionally)	Total Market, non-market cost / kWh	O	✓
RA2.2	Renewable Energy	kWh produced (regionally)	Total Market, non-market cost / kWh	O	✓
RA2.3	Commissioning/Monitoring	kWh reduced (regionally)	Total Market, non-market cost / kWh	O	✓
RA3.1	Fresh Water Quality	Acre-feet of downstream use (region)	Value / Acre feet of downstream use	O	✓
RA3.2	Potable Water Conservation	Acre-feet for consumptive use	Value / Acre feet for reliability	O	✓
RA3.3	Monitor Water Systems	Acre-feet of downstream use (region)	Included in RA 3.1		

© ASCE 2014

ID	Description	Units	Value	Data	Rel.
Climate and Risk					
CR1.1	GHG Reduction	Tons of GHG reduction	Value of GHG (avoid overlaps)	O	✓
CR1.2	Air Pollutant Reduction	Tons of CAC reduction by type	Value of CAC (avoid overlaps)	O	✓
CR2.1	Assess Climate Threat	Risk exposure (%) of extreme event	Cost of extreme event (or include in forecast?)	S	
CR2.2	Avoid Traps / Vulnerabilities	Needs more detailed specification	Captured in CR2.1 (?)		
CR2.3	Prepare For Long-Term Adaptability	Risk exposure (%) of extreme event (long-term)	Captured in CR2.1		✓
CR2.4	Prepare For Short-Term Hazards	Risk exposure (%) of extreme event (short-term)	Captured in CR2.1		✓
CR2.5	Manage Heat Island Effects	Change in Heat Index	Value / Heat index (human cost based)	S	
Quality of Life					
QL1.1	Community Quality Of Life	# of properties affected	Value / property of improved livability	O	✓
QL1.2	Sustainable Growth	# of properties affected	Captured in QL1.1		✓
QL1.3	Local Skills	Reduced unemployment	Reduced public unemployment cost per employee	S	
QL2.1	Public Health / Safety	Reduced # of accidents	Cost per injury	O	✓
QL2.2	Noise / Vibration	# of properties affected	% Increase in price / property	O	✓
QL2.3	Light Pollution	Reduced reflective light	Property value - based measure	L	✓
QL2.4	Community Mobility / Access	Reduction in vehicle miles traveled (VMT) (all modes)	Average value of reduced cost per VMT (across all modes)	O	✓
QL2.5	Alternative Modes	Reduction in VMT (all modes)	Captured in QL2.4		✓
QL2.6	Site Accessibility, Safety, Wayfinding	Miles of improved design	Average value / person-walking mile	L	
QL3.1	Historic / Cultural Resources	# of properties restored	Value per recreational visit	O	✓
QL3.2	Preserve Views / Character	# of properties impacted	WTP / person for aesthetics	S	✓
QL3.3	Public Space	Acres of public space	Average WTP / person for public space	O	✓

Data key for evidence: O = operational**; S =** some, site-specific**; L=**limited**;**
Related credit: ✓= overlapping credit

© ASCE 2014

Designing for the 21st Century: Sustainable Infrastructure in NYC

Dennis J. Stanford, PE, ENV SP
New York City Department of Environmental Protection
Bureau of Engineering Design & Construction
dstanford@dep.nyc.gov

Abstract

Our predecessors who planned, designed and built New York City's modern water supply and sewer systems in the late 1800s and early 1900s were able to create engineering wonders that left future generations the infrastructure to support growth, prosperity and public health in NYC. This long term vision of the future of NYC, provided a mandate for meeting the needs of the time while providing flexibility for future generations. Embedding these principles into modern project management is in itself a challenge. But only a full lifecycle view of infrastructure will ever be truly sustainable. New York City's Department of Environmental Protection (NYCDEP) is applying this long-term approach to address the challenges of climate change and the increasingly limited energy and material resources. This paper provides information about NYCDEP's process of defining and implementing their sustainability objectives within the context of an existing Project Delivery System.

Introduction

Our predecessors who planned, designed and built New York City's modern water supply and sewer systems in the late 1800s and early 1900s were able to create engineering wonders that left future generations the infrastructure to support growth, prosperity and public health in NYC. This long term vision of the future of NYC, provided a mandate for meeting the needs of the time while providing flexibility for future generations. Embedding these principles into modern project management is in itself a challenge. But only a full lifecycle view of infrastructure will ever be truly sustainable.

New York City Department of Environmental Protection (NYCDEP) is currently improving their existing project delivery framework to focus on delivery of sustainable infrastructure. NYCDEP supplies and distributes more than 1 billion gallons of high-quality water to nine million New Yorkers and visitors every day, and treats 1.3 billion gallons of wastewater daily to achieve the smallest possible impact on water quality in New York Harbor. Beyond these core utlity functions, we are also responsible for improving air quality, reducing noise pollution and protecting New Yorkers from hazardous substances.

NYCDEP manages a large capital program, $2.3 Billion annually, aimed at maintaning and expanding the city's water infrastructure. Predecessors who planned, designed and built NYC's water supply and sewer systems created engineering wonders that left future generations the infrastructure to support growth, prosperity and improved public health in NYC and its surrounding areas. These engineers did not know what the future would hold in terms of supply needs and water treatment, but they did have the wisdom and foresight to design in the flexibility for future generations of engineers to enhance and modify the

© ASCE 2014

system to meet the needs and challenges of their times. NYCDEP is applying this long term approach to address the vulnerabilities associated with climate change and the increasingly limited energy and material resources. Water infrastructure can be sustainable if planners and engineers look beyond the "problem equals solution" mentality with a broader social, economic and environmental solutions. It is with this triple-bottom line approach that NYCDEP will comprehend the true impacts of any solution. The first step is incorporating sustainable design practices into the NYCDEP existing project delivery system (PDS).

The evaluation included determination of best practices, streamline of processes, review of organizational structure, benchmark of the agency in comparison to other successful utilities, and identification of new tools to improve the delivery of the capital program. The outcome of the capital program management needs evaluation included development of a PDS, the 'DEP-Way' for project delivery.

In conjunction with the PDS updates, NYCDEP selected the Envision™ sustainable infrastructure rating system for application on capital projects. The Envision rating system is a valuable communication platform that allows stakeholders to identify and improve the triple bottom line (the balance of social, economic and environmental considerations), as well as a sustainability reporting tool and third party certification. NYCDEP has adopted the application of Envision™ throughout the lifecycle (planning, design, construction and operations) for current and future infrastructure projects.

Objectives

This paper provides information about NYCDEP's process of defining and implementing their sustainability objectives within the context of an existing PDS, including the following:

- Overview of NYCDEP's PDS
- Challenges of a large-scale municipal water utility with new-technology implementation
- Explanation of the process of identification of sustainability elements
- Description of sustainability elements incorporated into the PDS
- Overview of implementation strategies, including the Envision™ sustainable infrastructure rating system

Challenges

Over the last 3 years, NYCDEP's capital program has re-envisioned its role in the Design-Bid-Build project delivery framework to be a better steward for New York City. One goal of this effort is to build better projects by being a better owner. Initially focused on controlling escalating costs, uncontrolled scope growth, and schedule delays, the agency has expanded the system into all areas of project management. The program is designed to increase the quality of our designs while controlling budget. The agency is accomplishing this in part by incorporating sustainable practices throughout the core of the entire capital program, including updates to the PDS and application of the Envision™ rating system.

© ASCE 2014

The challenges that NYCDEP faces is similar to other large-scale municipalities in the nation's oldest cities. Nine million people rely on our aging infrastructure, in which maintenance and repair crews work around the clock to keep running. The dedicated groups, who compete for the limited economic and political support available, accomplish this task. Each group with its own long history and experience resulting in ingrained policies and standards form this system. At its core, sustainability blends the lines between "green" and "grey" engineered solutions to create outcomes that are more robust. Conflicts can often result from the introduction of new "greener" technology that may be difficult to fit into any existing category. While the intricacies and challenges water infrastructure may not be commonly understood in the public and political arenas, sustainable design concepts and approaches are. Sustainability is the bridge between what the public understands and what engineers and planners know a community needs. It is through this lens that engineers can determine potential solutions.

Project Delivery System

In considering potential solutions, engineers should look at the problem holistically over the full lifecycle to determine if the solution is truly sustainable or if they are only meeting the current problem. In designing New York City's Water supply system, the engineers of the time met greater construction challenges to ensure that the system was gravity fed. This has resulted in the low- or no-energy systems that we benefit today. In a time predating the Surface Water Filtration Rule and the Safe Drinking Water Act, the City of New York's engineers design for the hydraulic loads, built the needed connection vaults, and purchased land so that future engineers could meet the challenges.

NYCDEP upper management requested a "sustainability standard operating practice (SOP)" be developed for inclusion in the existing PDS. Early exploration into this task quickly made it apparent that one new SOP added to the PDS would neither have the capacity to cover everything involved, nor create a truly sustainable result for our projects. NYCDEP's Bureau of Engineering Design and Construction formed a Panel for Sustainable Infrastructure (Panel) to determine the needs and potential outcome for a sustainability component of the capital program.

The Panel was assembled to include multiple bureaus within NYCDEP, including bureaus overseeing design, construction, maintenance, operations and compliance. Core areas of sustainable design (energy efficiency, climate change, greenhouse gas emission, life-cycle assessment etc.) were divided among the areas of specialty from the Panel members, forming committees to address these areas as they relate to infrastructure projects. The Panel began incorporating relevant sustainable development practices and protocols into the PDS tools, existing and new SOPs, and standard contract documents. Recommendations for these updates were based on the findings of each committee.

The PDS updates addressed the structure and process for incorporation of sustainability concepts into project management. The Envision™ rating system proved to be appropriate for incorporation of sustainability concepts from planning and design through construction and operation of NYCDEP's standard water, wastewater, and stormwater projects. New

© ASCE 2014

York City recognized LEED as an industry standard for sustainable design. LEED impact on commercial and residential office spaces has been a sea change for the industry. The public infrastructure projects managed by NYCDEP, however, do not typically meet the prerequisites for LEED certification. Although most projects meet the requirements of LEED silver-level ratings, the occupancy, size and use designation omit the majority of water infrastructure assets operated by NYCDEP from.
In addition to incorporating sustainable development concepts into existing SOPs, the following new SOPs are identified for development:

- Sustainability Management Plan
- Preliminary Sustainability Workshop
- Sustainability Deep Dive Workshop
- Envision Workshop
- Energy conservation / GHG reduction plan requirements

Case Studies

Two of the NYCDEP projects selected as pilots for the Envision rating system are summarized as follows:

- The **Hannah Street Pumping Station** is currently at 30% design completion, and the Envision application is to be submitted in December 2013. At the time of ICSI 2014, the design phase and Envision evaluation will be complete. The goal for achievement level is gold certification.
- The **Rondout-West Branch Bypass Tunnel** is currently at 60% design completion, and has conducted the first Envision review workshop with the design team. At the time of ICSI 2014, the design will be complete, and the Envision application will be submitted.

These projects were selected because they represent two different services that NYCDEP provides (water supply and wastewater conveyance); they are located at distinctly different project sites (one is within the City limits, the other is rural up-state); and they are at different points in the planning and design phase. This helps identify how NYCDEP might apply Envision differently to each project, and better determine the current baseline for sustainability.

This program sought to build upon NYCDEP's highly successful PDS, and expand it to include operating and design parameters for improved delivery of sustainable infrastructure projects. The changes were made first through the existing structure and project delivery tools as a means to enact major revisions on a quick timeline. Rounding out the steps for adoption of new procedures, the transition included training and future efforts required to complete the cultural shift.

The findings of these changes include the following:

© ASCE 2014

- Early implementation of sustainable design practices reduces total cost
- Incorporation into existing and new SOPs and PDS is key to adoption
- Incorporation into contract documents and specifications improves project delivery
- Culture change and motivation are needed for greatest impact
- Application of Envision and collaboration among NYCDEP bureaus, clients and communities during planning and design highlights design issues and minimizes potential redesign

Conclusion

NYCDEP's PDS establishes a consistent method of project planning, and evaluation based on Agency goals and objectives. The PDS equips project teams with the tools and information needed to successfully complete the project on time and under budget. The systematic development and implementation of sustainable design practices, and introducing them into the existing PDS were critical to the sustainability program's success. The adaptability of the PDS made it possible to affect this kind of change in structure, policies, and protocols. This paper presents some of the items that were added to or revised within the PDS, and the methods used to convey the new information to employees.

The Envision rating system is a valuable resource for communicating what sustainability is and how it relates to NYCDEP's infrastructure projects. Envision makes it easier for project teams and stakeholders to assess the aspects of sustainability that are appropriate within each facility design. The rating system can help identify areas of current success as well as opportunities for improvement in each project. This paper presents two case studies for projects on which Envision was applied.

The cultural shift required for full-scale implementation proved the greater challenge. The paper addresses the messaging tactics used to train staff, facilitate project design collaboration, and gain operating bureau and other stakeholder buy-in.

In conclusion, BEDC has formalized attention to sustainable design for its capital program by establishing SOPs that focus efforts at critical times during the project lifecycle. This integration of sustainability as an aspect of project delivery has improved BEDC's performance across projects, especially with regard to energy usage and environmental stewardship. The concepts, methods and tools behind this success are not complex, and in fact they are closely mirror common techniques found throughout management systems. The key is making the planning, tracking, reporting and standardization readily apparent, giving leadership the ability to know how sustainable solutions meet present and future social, economic and environmental factors.

© ASCE 2014

Marrying Cost-Benefit Analysis (CBA) with BIM (CBA-BIM)

John C. Parker, Chief Economist Impact Infrastructure, LLC, Toronto, Centre for Social Innovation - Annex, 720 Bathurst Street, Toronto, ON, M5S 2R4, Canada; PH: (416) 659- 8560; email: John.parker@impactinfrastructurellc.com.

ABSTRACT

Building Information Modeling (BIM) is increasing the transparency and consistency of data in the planning, design, and operations phases of infrastructure projects (Autodesk 2014). Economic Cost-Benefit Analysis (CBA) is currently used on infrastructure projects to decide whether to proceed and, occasionally, which alternatives to design. Marrying CBA with BIM has tremendous potential to help in making sustainability and resiliency decisions related to infrastructure. This paper shows how CBA-BIM can produce better estimates of the social value of infrastructure, characterized in the Quality of Life category in Envision™, as well as addressing issues of social equity. CBA-BIM has the potential to measure the "resiliency of physical infrastructure across the full economic, social, and environmental dimensions of sustainability" (Institute for Sustainable Infrastructure 2012).

INTRODUCTION

Three innovations in the economic analysis have led to the ability to include Cost-Benefit Analysis (CBA) in Building Information Modeling (BIM) models

First, CBA's methodology, input data, and outputs are being standardized. Some examples of standardization from U.S., E.U., Canada, and Australia are: US department of Transportation (2014 and 2014a); US department of Transportation, Federal Highway Administration (2013); European Commission (2008); Treasury Board of Canada Secretariat (2013); and, Australia Department of Finance and Deregulation, Office of Best Practice Regulation (2013).

Second, risk analysis and meta-analyses[1] mean that uncertain or controversial inputs can be used. Finally, multiple account CBA allows for an understanding of all stakeholders' benefits.

[1] "a meta-analysis refers to methods that focus on contrasting and combining results from different studies, in the hope of identifying patterns among study results, sources of disagreement among those results, or other interesting relationships that may come to light in the context of multiple studies." Meta-analysis From Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Meta-analysis

© ASCE 2014

A linking of CBA's valuation methodologies, such as willingness to pay to a geographical information system (GIS), allows for CBA to add new data layers to a BIM model. CBA-BIM gives architects, engineers, designers, and planners access to a powerful tool that can help them decide what to build, how to build it, what the risks are, and who benefits.

THE BENEFITS OF CBA-BIM

The benefits of using CBA inside BIM are that: BIM defines relationships between objects and keep changes consistent and coordinated. So, as the design changes, so can the economic costs, benefits, and risks. BIM can show the economic business case for design alternatives while maintaining constraints such as building codes, design or safety criteria, and local or community standards. Also, BIM is visual, enabling better analysis, simulation, and communication. When combined with risk-based multiple account cost-benefit analysis, it becomes a powerful stakeholder visualization tool (Impact Infrastructure 2014).

Many of the benefits that are captured in the Envision™'s Quality of Life category are quantified and monetized in the Economic Companion Tools to Envision™ such as the Business Case Evaluator (BCE) (Impact Infrastructure 2014a, 2014b). Extending the monetization of the Envision™ credits to give them a geographical dimension in CBA-BIM further builds Envision™'s usefulness to the infrastructure community.

DISTANCE DECAY FUNCTIONS – LINKING ECONOMICS AND GEOGRAPHY

Willingness to pay distance decay functions are a critical link in the CBA-BIM story. They link how much people value infrastructure based on distance, use and income.

In geographical-based business case analysis we want to know which location for infrastructure will generate the most use and how it may be useful or harmful in addressing social equity.

"Our main conclusion is that distance decay relationships may well prove very useful in applied valuation work, since they provide a natural way of conceptualising the question 'who benefits?'" Hanley et al. (2003)

Distance decay is a geographical term which describes the effect that distance has on spatial interactions. It states that the interaction between two locales declines as the distance between them increases.

© ASCE 2014

Distance decay functions link the economic concept of willingness to pay (WTP) with geographical information systems. Typically, WTP is assumed to be invariant to distance within some arbitrary area (usually the area for which a survey of WTP was done) and that it is zero outside of this area. A more likely state of affairs would be that as you get further from an amenity you are willing to pay less for it since it will cost you more in travel time, and transportation costs, to get there. Also there is evidence that people may value not just the use of the amenity but also the option to use it as well. In addition they may value the bequest of a public good or service to future generations or perhaps, although they will never travel to use the amenity and so distance doesn't matter, it is important to them that others have access.

These arguments and findings (Bateman et al. 2001, Brainard et al 2002, 2003, Ghebreegziabiher et al. 2005, Hanley et al. 2003, and Pastor and Hipp 2001) suggest there are probably a couple of factors that need to be considered when linking economic WTP with a GIS. WTP will likely decrease as distance increases. But there may also be some value (bequest or altruistic value) that it unrelated to distance. A WTP distance decay function would therefore be a negatively-sloped relationship between WTP and distance. It could be linear (decreasing to zero at some distance) or non-linear (allowing for people far away from the facility to value it) as shown in the illustration (see Figure 1). The example uses values from a hypothetical WTP by households to close a quarry in a nearby national park (U.K. Government, Department for Environment, Food and Rural Affairs 2010).

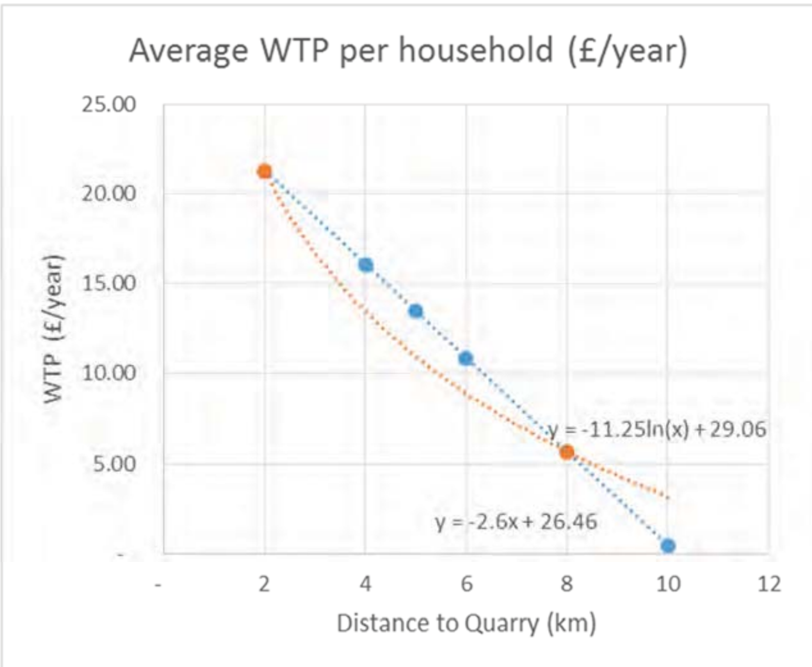


Figure 1. Willingness to Pay for Infrastructure Distance Decay Functions.

© ASCE 2014

Meta-analysis results that show that users are likely to pay more than non-users regardless of distance (see Figure 2). Also people are willing to pay more for big changes over small (Bateman et al. 2001) (see Figure 3):

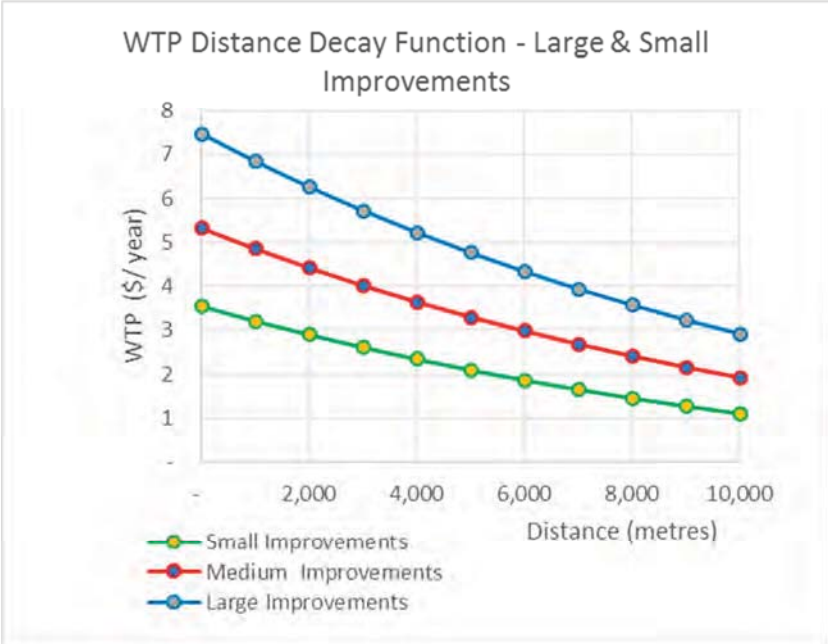


Figure 2. Willingness to Pay by Size of Infrastructure Improvements.

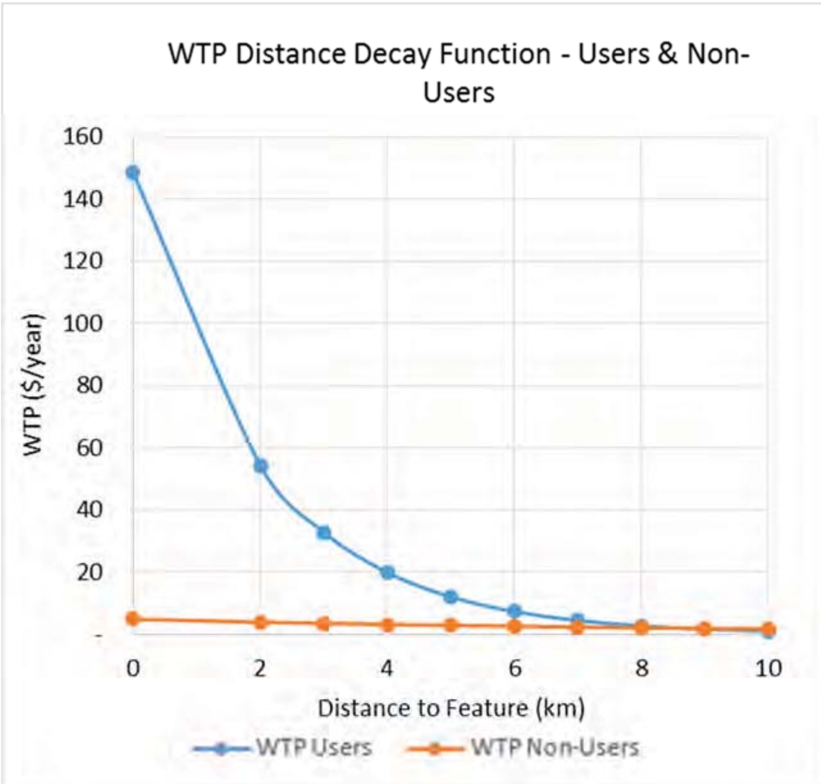


Figure 3. Willingness to Pay by Users and Non-Users of Infrastructure.

© ASCE 2014

EXAMPLE: TRANSIT INFRASTRUCTURE AND SOCIAL EQUITY

How much local residents will benefit from, or be harmed by, a new railway station close by is an important question from several perspectives. Infrastructure proponents need to know who will support the new station and how, for example, might taxes be adjusted to capture some of the increased property value associated with the station.

Envision^{TM} recognizes the importance of transit to quality of life (The relevant credits are: QL2.4 Improve Community Mobility and Access and QL2.5 Encourage Alternative Modes of Transportation) and, at higher levels, recognizes the importance of inclusion:

> *"The team works not only with decision-makers in adjacent facilities, et al., but also with local community officials. Design considerations have moved beyond access issues and now address the reduction of traffic congestion, improvements in walkability in the community, and other key measures of mobility and access."*
> *Institute for Sustainable Infrastructure (2012)*

The response of residential house prices to distance to a railway station is captured in a Dutch study (Ghebreegziabiher et al. 2005). The researchers "observe as big as 31% price difference for houses within 500m of the nearest station and houses beyond 15km for the station. … Apart from some irregularities at distance category 7,500 to 8,000 metres we see a smooth decline in the effect of distance on house prices." The empirical data are from 1985 to 2001 are shown along with the trend line (Figure 4):

© ASCE 2014

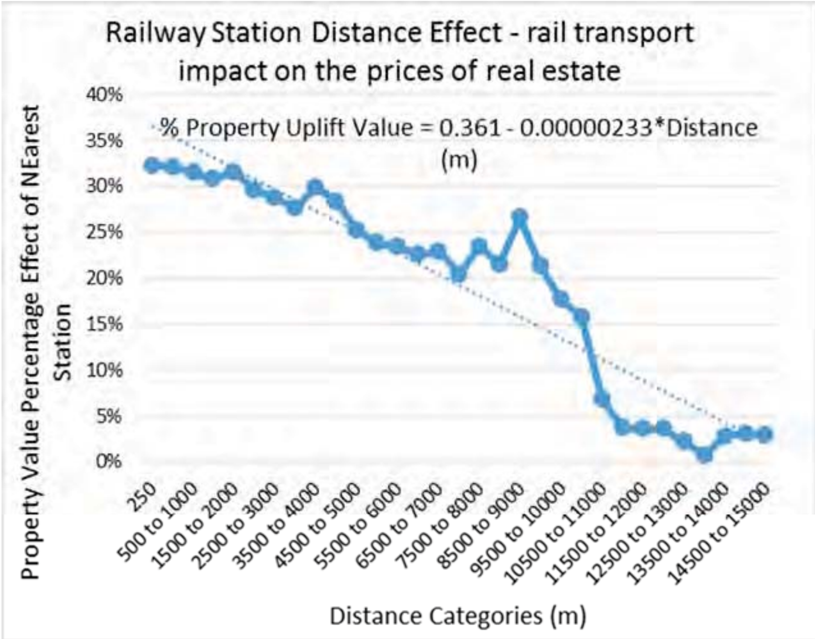


Figure 4. Railway Station's Effect on Property Prices.

People with low incomes may benefit from, or be harmed by, infrastructure improvements more than others with higher incomes who may have more options available to them. The distance-decay relationship can be refined for these factors. An example is that the economic value of transit differs for low income families.

Low income households may not have access to a car which may cost, say, $3 per trip (using data from Table 4.7 from Lewis and Williams 1999). They may have to rely on taxis that cost $6.10 per trip. Introducing transit at a cost of $1.50 per trip benefits both low and higher income groups by providing more affordable transportation. By calculating the area under their respective transit demand curves the value (WTP) to the two groups can be calculated. Figure 5 shows the demand for transit for low and Figure 6 shows the same for median income transit users.

© ASCE 2014

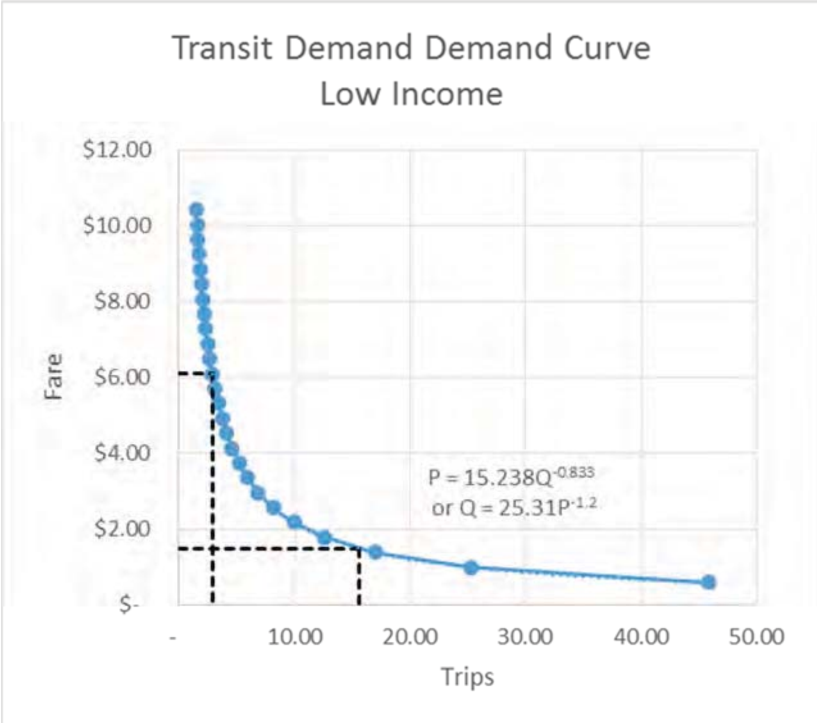


Figure 5. Transit Demand by Low Income Individuals.

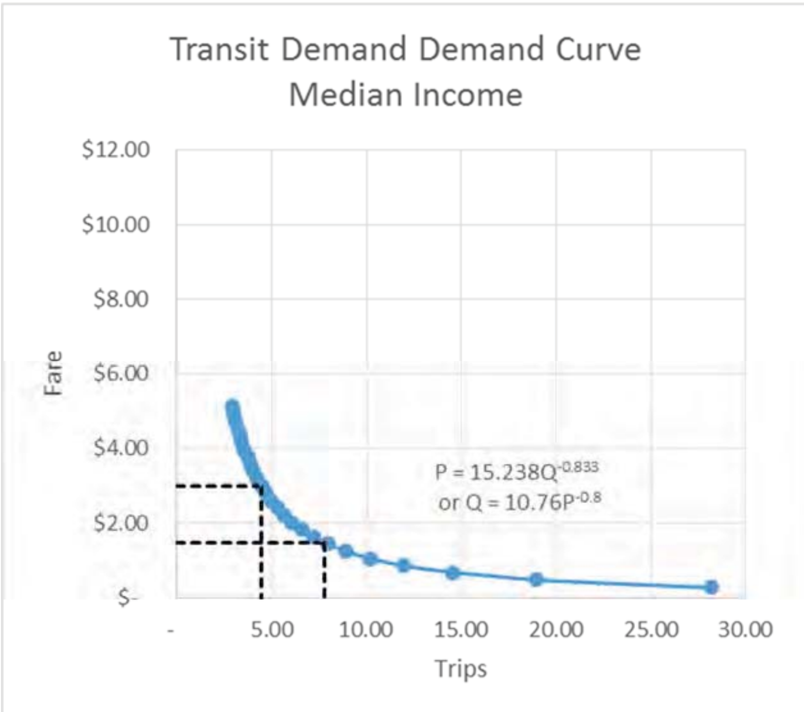


Figure 6. Transit Demand by Median Income Individuals.

© ASCE 2014

The value, in this case, for low income riders is $100 million. The value for median income riders is $20 million. The low income value is, therefore, a factor of 5 times greater.

The Transit BCE Economic Companion Tool for Envision™ (Impact Infrastructure 2014c) includes the benefits to low income families.

When the total value number for the low income segment is translated into a WTP per rider per year it can then be combined with a distance decay function that uses meta-analysis results from the literature (Bateman et al. 2001, Brainard et al 2002, 2003, Ghebreegziabiher et al. 2005, Hanley et al. 2003, and Pastor and Hipp 2001) to differentiate between low and median income earners. The resulting relationship (Figure 7) shows the benefit of new transit to differing income groups along with their distance to the transit station.

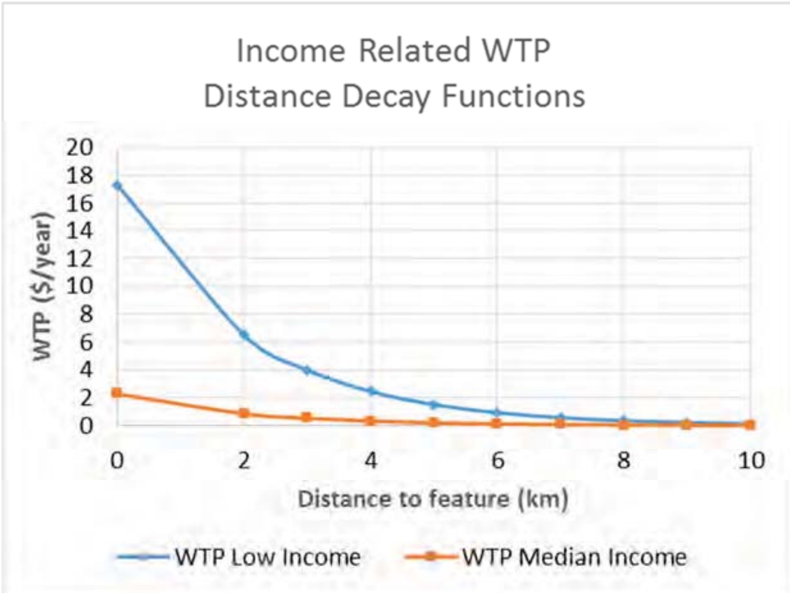


Figure 7. Willingness to Pay Distance Decay Functions for Low and Median Income Users.

Mapping low income neighborhoods and their distances to the proposed transit station the income-differentiated distance decay allows for estimating the benefit to these neighborhoods. The ability to answer the "what's in it for me" question becomes a powerful tool to build stakeholder support for infrastructure projects.

The example of the transit stop demonstrates that how valuable an infrastructure asset is in a city's sustainability portfolio depends on its context. For example a park is more valuable the fewer parks are nearby (Impact Infrastructure 2014d). The same relationships can be used to measure the value of dis-benefits of localized effects of infrastructure projects such as pollution, noise, and odor. Some example of these effects by different income group are provided below. CBA-BIM captures these economic and geographical relationships.

© ASCE 2014

In the same vein, we are learning that resiliency must consider relationships and inter-dependencies. A city's resiliency to climate risks is only as strong as its weakest infrastructure link. The city- or region-wide aspects of sustainability and resiliency can only be addressed in the larger context of BIM models that consider the context of infrastructure and its geographical, strategic and economic relationship to other infrastructure.

CBA-BIM FOR ACCURATE SOCIAL VALUE OF INFRASTRUCTURE & SOCIAL EQUITY CONSIDERATIONS

More social equity impacts from infrastructure are found in the literature. One study (Pastor and Hipp 2001) found that it was more likely that toxic waste dumps were sited in poor neighborhoods than low income people moving to where these sites were because of lower house prices.

Interesting equity issues are raised by authors (Brainard et al. 2003) who examine the extent to which inequalities in transportation noise exposure are present. Disparities were observed in estimated noise exposures and levels of socio-economic deprivation. Almost the same authors (Brainard et al. 2002) have studied air pollution. They find the overall distribution of the non-immigrant, native ethnic group (labelled as '>90% White') enjoys substantially lower levels of pollution than does the Afro-Caribbean group. Also, while both non-immigrant and some immigrant groups respond to improvements in personal socio-economic circumstances by relocating to lower-pollution neighborhoods, there ae other groups are less responsive to such improvements.

Similar to the geographical impacts of noise of different socio-economic groups, local pollution has different economic damage costs depending on where the pollution is emitted and where the people, buildings, and crops are. In dense urban areas, damages to health and buildings are more than in less dense urban environments. Damages to health and buildings in rural locations are less again. For projects that change pollution, BIM allows local air quality to be modeled based on the number of trees, distance to pollution source, elevation, density and value of people, buildings, and crops. It can show which neighborhoods benefit and by how much. Distance and noise effects are also dealt with in the Ghebreegziabiher et al. (2005) rail study.

CBA-BIM FOR INFORMED, SOCIALLY EQUITABLE, AND DEFENSIBLE SUSTAINABLE INFRASTRUCTURE & RESILIENCY DECISIONS

Currently planners, engineers, architects and designers make many decisions that affect the sustainability of a project without the aid of a business case, or even a consistent set of data. CBA-BIM provides the standard framework and data to make consistent, sustainable and value-enhancing decisions.

For example, tree density, often easily available and able to be pulled into a BIM model, affects the urban heat-island effect. Temperatures in excess of a certain

© ASCE 2014

threshold can kill people. Population density layered on top of tree density allows economists to put a value to how trees reduce the number of people dying from excessive heat events For example the vulnerability is shown in Pima Association of Governments (2014) and Tucson (2014).

To add to the transit example above, in CBA-BIM, transit locations, trail and bike path information can be overlaid with income, health (Toronto 2014), and job information. Low income neighborhoods can benefit from increased access to job opportunities when there is an improvement in transportation; this benefit can be quantified (with care being exercised not to double count possibly overlapping benefits). So can the economic value of reductions in obesity rates or diabetes risk that can result from increased access to transportation or increased recreational use space. By simply placing a new transit stop in a BIM model and triangulating the distances to job prospects and health-care centers, economic benefits and health benefits can be calculated, monetized and compared with costs. When infrastructure's benefits to public health, the economy, and disadvantaged groups are considered, Envision™'s full purpose is being realized:

"Its purpose is to foster a necessary and dramatic improvement in the performance and resiliency of physical infrastructure across the full economic, social, and environmental dimensions of sustainability." Institute for Sustainable Infrastructure (2012)

CONCLUSION

The CBA-BIM framework is a combination of existing and available tools. CBA-BIM's use in planning and designing sustainable and resilient projects will mean that the value of infrastructure, its sustainability, and its impact across different groups can now be reliably be estimated and incorporated into the planning and design process. Armed with this information, decisions that are good for the environment, society and neighborhoods can be made.

Extending the monetization of the Envision™'s Quality of Life credits to give them a geographical dimension in CBA-BIM further builds Envision™'s usefulness to the infrastructure community.

REFERENCES

Australia Department of Finance and Deregulation, Office of Best Practice Regulation (2013). "Best Practice Regulation Handbook - Appendix E. Cost-benefit analysis" http://www.finance.gov.au/obpr/proposal/handbook/appendix-E-cost-benefit-analysis.html

Autodesk (2014). “BIM: Building Information Modeling – What is BIM?” http://www.autodesk.com/solutions/building-information-modeling/overview

Bateman, I., Georgiou, S., Lake, I., (2001). “The Aggregation of Environmental Benefit Values: A Spatially Sensitive Valuation Function Approach”, CSERGE Working Paper EDM 05-04, http://www.econstor.eu/bitstream/10419/80283/1/506637611.pdf

Brainard, J.S., Jones, A.P., Bateman, I.J., Lovett, A.A., Fallon, P.J., (2002). “Modelling environmental equity: access to air quality in Birmingham UK.” *Environment and Planning* A, 34, pp. 695-716. http://www.envplan.com/abstract.cgi?id=a34184

Brainard, J.S., Jones, A.P., Bateman, I.J., Lovett, A.A., (2003). “Modelling environmental equity: Exposure to environmental urban noise pollution in Birmingham, UK”, CSERGE Working Paper EDM, No. 03-04 http://www.econstor.eu/bitstream/10419/80295/1/367781328.pdf

European Commission (2008). “Guide to Cost-Benefit Analysis of Investment Projects” http://ec.europa.eu/regional_policy/sources/docgener/guides/cost/guide2008_en.pdf

Ghebreegziabiher, D., Pels, E., Rietveld, P., (2005). "The impact of rail transport on the prices of real estate: Empirical study of the Dutch housing market." Department of Spatial Economics, Free University, De Boelelaan, Amsterdam, http://www.ekf.vsb.cz/export/sites/ekf/projekty/cs/weby/esf-0116/databaze-prispevku/clanky_ERSA__2005/748.pdf

Hanley, N., Schläpfer, F., Spurgeon, J. (2003). “Aggregating the benefits of environmental improvements: distance-decay functions for use and non-use values”, Journal of Environmental Management 68, 297–304.

Impact Infrastructure (2014). “Triple Bottom Line Business Case Analysis for Infrastructure Planning and Design”, http://Impactinfrastructurellc.com/blog/?p=417

Impact Infrastructure (2014a). “The Business Case Evaluator for Stormwater Management Best Management Practices Released”, http://Impactinfrastructurellc.com/blog/?p=233

Impact Infrastructure (2014b). “Business Case Evaluator™ Documentation and Spread Sheets”, http://impactinfrastructurellc.com/tools.html

Impact Infrastructure (2014c). “Business Case Evaluator for Transit”, http://impactinfrastructurellc.com/blog/?p=519

Impact Infrastructure (2014d). “The Business Case for Green – CBA-BIM Style”, http://impactinfrastructurellc.com/blog/?p=378

Institute for Sustainable Infrastructure (ISI) (2012). “Envision 2.0 A Rating System for Infrastructure” Guidance Manual, Zofnass Program for Sustainable Infrastructure

© ASCE 2014

at the Harvard University Graduate School of Design and The Institute for Sustainable Infrastructure.

Lewis, D., Williams, F.L., (1999), *Policy and planning as public choice: Mass transit in the United States*. Vol. 5. Ashgate, http://www-coop.fta.dot.gov/documents/Policy_and_Planning_as_Public_Choice.pdf

Pastor, M., Sadd, J., Hipp, J., (2001). "Which Came First? Toxic Facilities, Minority Move-In, and Environmental Justice?" *Journal of Urban Affairs* 23(1), 1–21, https://sustainability.water.ca.gov/documents/18/3407876/WHICH+CAME+FIRST.pdf

Pima Association of Governments (2014). "Heat vulnerability and tree shade opportunities map", http://gismaps.pagnet.org/PAG-GIMap

Toronto (2014). "Spatial Relationship Between Diabetes Prevalence Rates and Travel Time to the Nearest Park or Schoolyard by Public Transit" http://www.torontohealthprofiles.ca/test/a_documents/TM_allCateg_maps/TM_maps_SRBTSVchar/16_SRBTSV_LISA_DM_x_Recs-PTwalk_N.pdf

Treasury Board of Canada Secretariat (2013). "Canadian Cost-Benefit Analysis Guide: Regulatory Proposals" http://www.tbs-sct.gc.ca/rtrap-parfa/analys/analystb-eng.asp

Tucson (2014), "9th Urban Heat Island Workshop", http://impactinfrastructurellc.com/blog/?p=663

U.K. Government, Department for Environment, Food and Rural Affairs (eftec) (2010). "Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal - Case Study 7 – Using GIS in Valuing Ecosystem Impacts" https://www.cbd.int/financial/values/unitedkingdom-case7.pdf

US Department of Transportation (2014). "Benefit-Cost Analyses Guidance for TIGER Grant Applicants - TIGER BCA Guidance" http://www.dot.gov/policy-initiatives/tiger/tiger-bca-guidance-2014

US Department of Transportation (2014a). "TIGER BCA Resource Guide" http://www.dot.gov/policy-initiatives/tiger/tiger-bca-resource-guide-2014

US Department of Transportation, Federal Highway Administration (2013). "Benefit-Cost Analysis - Asset Management" http://www.fhwa.dot.gov/infrastructure/asstmgmt/primer05.cfm

© ASCE 2014

EnvISIon™ Sustainability Rating: Sun Valley Watershed Multi-Benefit Project

Rossana D'Antonio[1], Youn Sim[1], Joseph Li[1], Margaret Terrell[1], Richard Gomez[1], Christine Wartman[1] Sarah Ahmed[1]

[1] Department of Public Works, County of Los Angeles, 900 S. Fremont Ave., Alhambra, CA 91803

ABSTRACT

The Sun Valley Watershed Multi-Benefit Project is a first-of-its-kind venture geared at managing storm water for the Sun Valley Watershed to provide flood protection, improved watershed health, an increase in open space and recreational opportunities, and an increase in wildlife habitat.

The Sun Valley Watershed is historically plagued with several watershed health issues such as severe flooding, poor water quality, and industrial and residential urbanization. The watershed lacks a comprehensive storm drain system, and consequently suffers from chronic, severe flooding during moderate storm events. During these events, intersections are inundated and stormwater on major streets resemble river flows.

In 2001 Los Angeles County led a comprehensive effort to address all of the watershed health issues in Sun Valley through a multi-benefit approach. A group of stakeholders was assembled to form the Sun Valley Watershed Stakeholders Group. The group aims to develop long term solutions to the chronic flooding issues that provide additional benefits to the community. This group consists of local and federal agencies, government offices, environmental groups, local businesses, conservation agencies and residents of the community. The mission of the Sun Valley Watershed Stakeholders Group is to solve the local flooding problem while retaining all stormwater runoff from the watershed, increasing water conservation, recreational opportunities, and wildlife habitat, and reducing stormwater pollution. This led to the development of the Sun Valley Watershed Management Plan which identified fifteen pilot components that collectively achieve the established watershed goals. Since the development of this plan, four of the components have been constructed and an additional four are in the planning and design phases. The Sun Valley Watershed Multi-Benefit Project encompasses the following eight constructed and proposed components. See **Figure 1** for the watershed map illustrating the locations of eight components.

1. Valley Steam Plant
2. Tuxford Green
3. Sun Valley Park Drain and Infiltration System
4. Rory M Shaw Wetlands Park
5. Sun Valley Watershed Upper Storm Drain System and Recycled Water Line
6. Elmer Avenue Neighborhood Retrofit
7. Elmer Avenue Paseo
8. Whitnall Powerline Easement

© ASCE 2014

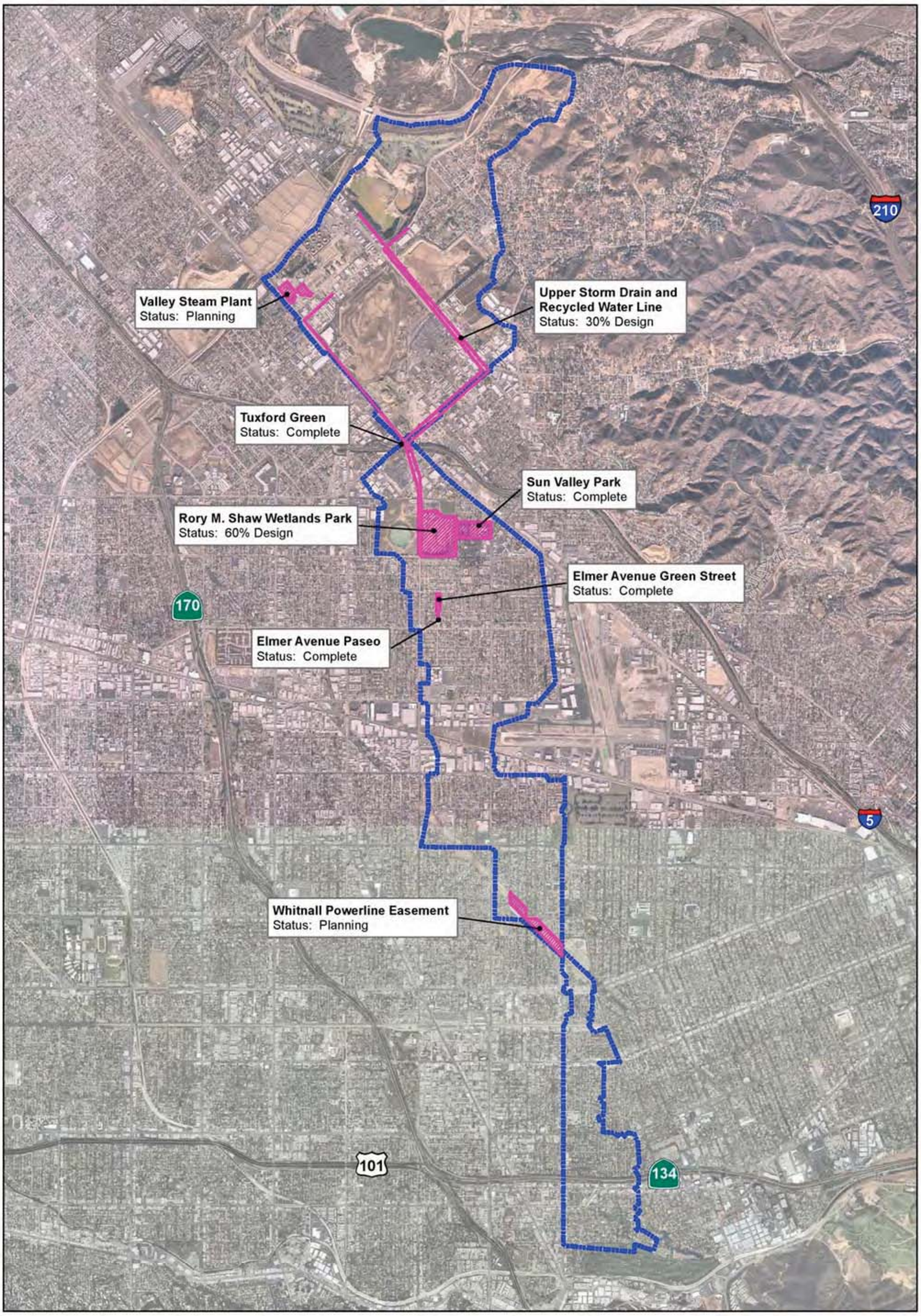


Figure 1: Sun Valley Watershed Multi-Benefit Project Components

© ASCE 2014

The Sun Valley Watershed Multi-Benefit Project represents a blue ribbon project that has successfully integrated a balanced approach in design in an economically, environmentally, and socially-responsible way.

INTRODUCTION

The Sun Valley Watershed encompasses approximately 2800 acres of urban area located within the northwest region of the City of Los Angeles. The watershed area is primarily zoned for industrial, commercial, and pockets of residential uses. The area is historically plagued with local flooding and poor water quality. The Sun Valley Watershed Management Plan was developed by Los Angeles County Department of Public Works to mitigate for flooding and water quality issues and provide the community with benefits such as recreation, public space, and natural habitat restoration.

The Sun Valley Watershed Multi-Benefit Project is a collection of eight constructed and proposed components from the Sun Valley Watershed Management Plan. The project components include: Valley Steam Plant, Tuxford Green, Sun Valley Park Drain and Infiltration System, Rory M. Shaw Wetlands Park, Sun Valley Watershed Upper Storm Drain System and Recycled Water Line, Elmer Avenue Neighborhood Retrofit, Elmer Avenue Paseo, and the Whitnall Powerline Easement.

The project planning and design embrace one of Los Angeles County's core values of "sustainability" and the Department's vision of "creating communities…sustaining life". The project mission is to solve the existing local flooding problem while retaining all stormwater runoff from the watershed, increasing water conservation, recreational opportunities, and wildlife habitat, and reducing stormwater pollution. When complete, the project will transform an urban community dominated by heavy industry and trucks to create one that is pedestrian-friendly and accessible to the local residents. It will restore native habitat and public space to enhance the community aesthetics and promote healthier living.

The management plan commits Los Angeles County to develop sustainable infrastructure projects by encouraging local stakeholder involvement and input to develop sustainable designs that will improve the quality of life of the community. The EnvISIon™ rating system is a highly effective tool to measure the levels of sustainability for such a project and consists of five categories of sustainable design: Quality of Life (QL), Leadership (LD), Natural World (NW), Resource Allocation (RA), and Climate and Risk (CR). These categories include credits for the positive social, economic, and environmental impacts to the community in the planning, design and construction of infrastructure projects.

The EnvISIon™ rating exercise has proved the Sun Valley Watershed Multi-Benefit Project very sustainable. The project rated very well in 3 of 5 categories: Quality of Life, Leadership, and Natural World. The rating for the Resource Allocation and Climate and Risk categories were not as high. The following paper will address the project strengths and weaknesses for each category and provide support for the rating results.

© ASCE 2014

ENVISION™ RATING RESULTS

Quality of Life (QL)

The proposed project rated very well in the Quality of Life category. The Sun Valley Watershed Multi-Benefit Project manages storm water for the Sun Valley Watershed to provide flood protection, improved watershed health, an increase in open space and recreational opportunities, and the restoration of natural habitats. The transformation of an inert landfill to a flood control detention basin, wetland, and park greatly benefits the local community at many levels. The project eliminates local street flooding during moderate storm events, which enhances public safety and health. The project also includes storm water quality improvement measures such as wetlands and trash exclusion devices. It will provide the community with access to much needed public space for social interaction and recreation.

Some improvements that can enhance the QL rating include adding integrated wayfinding signage and encouraging alternate modes of transportation by including bicycle paths into the plans and reducing parking spaces to encourage alternative modes of transportation.

Leadership (LD)

Los Angeles County provided superior leadership and coordination in developing the Sun Valley Watershed Management Plan. The implementation of the management plan is dependent on strong partnerships and collaborations between various agencies, environmental groups, political offices, and the community. The project components were developed and designed based on key stakeholder involvement. In some instances, the community had direct input in the project design such as choosing the recreational amenities in the public park. Los Angeles County demonstrated exceptional leadership and commitment to the project by performing extensive outreach, purchasing a landfill site, incorporating sustainable design, and improving community living. A long-term monitoring and maintenance plan was also implemented effectively to maintain the viability and function of the project.

Performance in this category was limited by not pursuing high level change of policies that may create barriers to implementing sustainable infrastructure. The project complied with applicable regulatory permits.

Resources Allocation (RA)

The project category had a lower rating for Resource Allocation mainly due to Los Angeles County's policy and standard practices for design. For example, the standard contract specifications do not specify for contractors to use renewable energy, regional materials, recycle their byproducts, or use products from manufacturers that support sustainable practices. However, the Project Engineer may consider these provisions for the future components of the project. Los Angeles County did not perform a net embodied energy study or commission and

© ASCE 2014

monitor energy systems for the project as these may be cost prohibitive for a publicly funded infrastructure project.

The project promotes water conservation by capturing, treating, and infiltrating stormwater to local aquifers as a means to protect fresh water availability for the region. Native plants are used throughout the project to minimize irrigation usage. A recycled water line is proposed to irrigate the Rory M. Shaw Wetlands Park component of the project.

Natural World (NW)

The project rated very well in the Natural World category primarily due to the main scope of the work: restoration of floodplain functions and the management of stormwater. The construction of detention basins and wetlands will store and treat stormwater respectively from the affected watershed prior to ground infiltration for recharge of local aquifers. The project also restores native habitat to the project site with native landscaping. The project incorporates wetlands, infiltration trenches and basins, bioswales, and treatment trains to reduce pollutant load concentrations prior to ground infiltration. Construction Best Management Practices are stipulated and implemented during construction to prevent surface runoff from the site. A detailed hazardous material removal plan was developed to contain, handle, and remove contaminated material safely from the project site.

Two credits, the "Preserve Prime Habitat" and "Preserve Prime Farmland" credits were not applicable because the project site is fully developed and urban in nature.

Climate and Risk (CL)

The project rated relatively low for the Climate and Risk category. Los Angeles County does not perform comprehensive life cycle carbon analysis and heat island calculations on the infrastructure projects. These tasks may be considered, but are probably cost prohibitive and provide no significant changes to the project.

A statewide climate impact assessment study, the California Adaptation Planning Guide, was completed by the California Natural Resource Agency. The adaptation considerations for the "South Coast Region" resulting from this study include: "sea level rise, increased wildfire risk, public health, socioeconomic and equality impact, and water supply." The project prepares for long term adaptability for climate variations such as drought and floods by adjusting the operational levels of the detention and infiltration basins. The transformation of a landfill to a functional wetlands and park will substantially improve community livability. Dust and pollutants that are created from the unloading of waste material will cease to exist. Haul traffic of diesel trucks which is used to service the landfill site will be eliminated, and the air quality will improve as a result.

© ASCE 2014

POSSIBLE PROJECT IMPROVEMENTS FOR ENHANCED SUSTAINABILITY

As a result of this rating exercise, several project improvement options were identified to potentially enhance the project's rating. The proposed options may be considered not only for this particular project but also for future sustainable project planning:

- Use renewable energy sources (solar powered lighting or pumps)
- Use stormwater for irrigation purposes in landscaped areas and open spaces
- Consider a sustainable procurement policy for purchasing various materials for facility maintenance/repair or new construction
- Consider special provisions in design manuals, construction specifications, and bid packages, mandating at the maximum extent practicable, recycled, reused, and regional material uses, and increasing local recruitment of work force
- Increase integration between infrastructure sectors
- Conduct carbon lifecycle analysis and climate impact studies for enhanced evaluation of project impact or benefits

BENEFITS OF USING ENVISION™

During the rating exercise, many benefits of using EnvISIon™ were identified for Los Angeles County's civil infrastructure planning. Below are some of the key benefits identified:

- Provides a good tool/checklist and guidance during initial stage of project planning or concept development
- Introduces more sustainable ideas and elements to make projects meet Los Angeles County's sustainability goals
- Provides opportunities to evaluate Los Angeles County's current practices toward sustainability goals
- Provides an opportunity to consider new funding strategies that would support sustainability goals

CONCLUSION

The Sun Valley Watershed Multi-Benefit Project is a first-of-its-kind large scale venture by Los Angeles County geared towards flood control, stormwater quality improvement, stormwater conservation with added community benefits such as public space, recreation, and restoration of natural habitat. The project consists of eight components from the Sun Valley Watershed Management Plan. The Sun Valley Watershed Management Plan was developed to provide comprehensive long term solutions for stormwater management that is sustainable and improve the livability of the community.

© ASCE 2014

Envision™ as a Solution to Standards and Capacity Challenges

John F. Williams[1]

[1] Chairman and CEO, Impact Infrastructure, LLC, 230 Park Avenue, 10th Floor, New York, New York 10169; PH (914) 224-7639; FAX (212) 808-3020; email John.williams@ImpactInfrastructureLLC.com

ABSTRACT

The need for investment in infrastructure and public buildings continues to grow with no end in sight. Deferred maintenance and expanding service demands are compounding the funding challenge. The days of federal ear marks have ended and formula grants are being replaced by highly competitive merit based programs. In the mean time, private sector Impact Investors are eager to deploy pension fund, family office, socially responsible, and ESG sourced capital into infrastructure and public building projects. There is enormous potential to more than offset public funding shortfalls with impact capital but, barriers to entry exist. Project sponsors will need to convince merit based funding programs and private sector investors of the **value** associated with their initiatives. In the new normal, where public or private capital is concerned, infrastructure delivery professionals will need to learn to compete. Competition will be driven metrics, assessment standards, and access to capacity. It is going to be complicated for a while as the lack of formal standards, adequately trained and equipped evaluation capacity presents a major challenge to the removal of funding barriers.

This paper describes how Envision™ (Envision) can serve as a solution to the standards, training, and capacity challenges to project funding while creating a competitive advantage for Envision Professionals, their project sponsors, and stakeholders as they search and compete for funding to implement their sustainable infrastructure programs.

INTRODUCTION

GET IN THE GAME. The infrastructure delivery industry is facing a major game changer in the way projects will be funded. While projects are being delayed and even cancelled, many planning and design practitioners wait on the side lines. What they do not realize is that solutions to funding dilemmas largely rely on their knowledge, skill, and initiative.

© ASCE 2014

According to the US SIF Foundation, Report on Sustainable and Responsible Investing Trends in the United States (2012), decreasing levels of public funding are creating shortfalls that could well be offset by private sector impact capital from sources including pension funds, family offices, foundations, socially responsible and environmental, social and governance (ESG) investors who control nearly $30 trillion worldwide. The lack of metrics and standards for project rating and valuation combined with a shortage of capacity to evaluate projects are major barriers to accessing merit funds and to the unleashing of impact capital. The formalization of the emerging standards and mastery of project evaluation skills are key to unlocking access to capital that will advance the sustainable infrastructure cause.

The infrastructure delivery industry faces a new reality. More than ever, project sponsors will have to compete for the resources needed to implement their programs. The US DOT's Transportation Investment Generating Economic Recovery (TIGER) Grant Program initiated under the ARRA of 2008 offers a powerful hint of things to come.

TIGER is billed by US DOT Secretary Foxx as a "highly competitive program ...offering one of the only federal funding possibilities for large, game-changing multi-modal projects." Each round of funding (five completed since 2008) have drawn huge numbers of applications and demand, according to Transportation for America, Tracking TIGER Grants, as of 2013 that exceeded $136 Billion for a total funding pool of $3.57 Billion. The ENO Center for Transportation in its report entitled, Lessons Learned from the TIGER Discretionary Grant Program (2013), reported that there were 5,200 applicants through 2013 with 186 selected through 2012 confirming the level of intensity in competition for funding. One element of the selection process focuses on the use of benefit-cost analysis (BCA) to evaluate long-term economic outcomes in the program application and evaluation process. "Other discretionary USDOT programs, such as the Transportation Infrastructure Finance and Innovation (TIFIA) loan program and the Transit New Starts grant program, had also required economic analysis in their application and evaluation processes. But TIGER was the first discretionary federal transportation program that required project applicants to estimate total expected project benefits and weigh them against project costs." The ENO report went on to state that the use of BCA presented problems for project applicants as many had, "little or no experience with this type of analysis and USDOT had little experience using it within discretionary grant programs."

© ASCE 2014

TIGER showed that metrics, standards and skilled capacity matters. Infrastructure delivery professionals that "get it "and, get in the game early will have a significant advantage. But how?

STANDARDIZATION

That's where Envision™ (Envision) comes in. Envision has what it takes to achieve standardization in the North American infrastructure delivery industry. It has achieved:

Credibility by providing a transparent process resulting from broad industry participation and consensus driven decisions as to how to appropriate assessment categories, weighting and scoring. It is designed to apply across a wide variety of infrastructure projects. It was expanded to incorporate attributes associated with the Zofnass Rating System developed with industry input by leading researchers and academics at Harvard's Graduate School of Design;

Scale thanks to the three associations that back the Institute for Sustainable Infrastructure (ACEC, APWA and ASCE) which represent nearly 600,000 capital program influencers across North America as well as a rapidly growing list of ISI charter members (dozens of public and private entities) as well as ISI trained and accredited professionals (more than 2,000 Envision Sustainability professionals – ENV SP -- in the first two years);

Affordability thanks to modest fees for membership, training and project evaluation; and the ability to,

Deploy in mass thanks to the power of the Internet, ISI's member network and influence of its practitioners.

Envision with Economics and Risk Assessment

Envision features an economic and risk assessment companion tool referred to as the Business Case Evaluator or BCE. The BCE was developed by Impact Infrastructure, LLC (ii) in consultation with the ISI Economics Committee (Committee). ii started with state of the art cost benefit and risk analysis and expanded its approach based on applied experience with the Sustainable Return on Investment (SROI) Framework which was introduced into the public domain in 2009. SROI has accrued a track record of over $10 Billion in project assessments. The framework is used by a growing number of consulting firms. Elements of SROI can be found in USDOT TIGER BCA Resource Guide 2014.

The BCE expanded beyond SROI to include multiple account cost benefit analysis (MACBA). MACBA identifies and quantifies the degree to which there

© ASCE 2014

are winners and losers among those impacted by a given project. The expansion also included features that quantify value based on distance and interrelationships and willingness to pay for sustainable infrastructure. The BCE is presented in spreadsheet form supported by the BCE User Manual and full documentation making it usable by planning and design practitioners as well as due diligence teams in the financial sector. Like SROI, **the BCE has been committed to the public domain.** Users can access it free of charge through the ISI website (www.sustainableinfrastructure.org/resources). ii has committed to upgrading and maintaining currency of the BCE through 2016.

The combination of Envision with the BCE economic and risk assessment companion tool are products of a process that began with an industry-wide motivation for the creation of a single sustainability rating system for infrastructure projects. The three associations that created ISI and collaboration with the Zofnass Program for Sustainable Design Harvard's Graduate School of Design resulted is a common vision - "Envision." ISI enlisted a diverse collection of dozens of additional charter members and other supporting organizations to create political support needed to sustain the organization and its vision. An internal governance structure was created manage the transition of Envision from concept to accepted practice. Envision was expanded to include economics and risk assessment to provide rating capacity at a scale and with a track record that that no other system is replicating.

Objectivity, Transparency, and Comparability

Efforts to create a standard approach to infrastructure rating are reinforced by changes in political and business climates, increasing competition for financial resources, growing reliance on market based forces, and advances in technology. According to the U.S. Securities and Exchange Commission (Concept Release: International Accounting Standards 17CFR Parts 230 and 240, FILE NO. S7-04-00 – Supplemental Information) the world's financial centers have grown increasingly interconnected presenting the growing potential for global investors to find their way to participation in domestic infrastructure projects. According to the SEC, "Markets allocate capital best and maintain confidence of the providers of capital when the participants can make judgements about the merits of investments and comparable investments and have confidence in the reliability of the information provide."

Envision with the BCE provide an objective, transparent means of highlighting for comparison, project merits and value including *Financial ROI + External Economic + Social and Environmental Costs and Benefits x Adjusted for Uncertainty and Risk = Value for Money*. Because the BCE is based on globally

© ASCE 2014

accepted cost benefit practices that have been embraced by federal agencies and are the default standard for evaluating infrastructure and building projects, the tool is responsive to the need for a comprehensive, generally accepted basis of accounting. Further, the objective and transparent nature of the BCE addresses the need for high quality assessment that can be subjected to rigorous interpretation and application. The combination of Envision and the BCE offer a comprehensive rating and economic assessment tool that meets implied criteria set forth by the SEC for standardization as described below:

ISI's diverse membership and consensus based development of Envision addresses the need for **a high quality rating standard**.

Provisions for the independent verification of Envision Ratings address the need for **audit capacity** so that the market has assurances that the rating process/standard is rigorously interpreted and applied profession-wide for quality assurance and that issues and problematic practices are identified and resolved in a timely manner.

Reliance on independent third party auditor generally associated with professional consulting firms or public agencies and that are regulated by professional performance standards address the need for **effective quality controls**.

ISI's ongoing commitment to continuing education and training, effective monitoring, industry reach and depth as well as the ability to deny or repeal Envision credentials in the event that of disciplinary action, address the need for profession-wide **quality assurance**.

The planning, design and financial professionals each have their own professional registration and licensing requirements address the need for active **regulatory oversight.**

Project Bundling

Project size and disparity present additional barriers to impact capital participation in infrastructure and building projects. It is common for those types of projects to have capital costs that are lower than can be efficiently financed in the private sector. Major institutional investors including public pension giants CalPERS and CalSTRS seek investment opportunities that exceed $250M or more leaving smaller projects out of their consideration. Institutional investors overcome the monetary threshold challenge by bundling investments. Infrastructure and building projects are difficult to bundle because each project is unique and very difficult to compare. Envision with the BCE address the

© ASCE 2014

comparability challenge by providing a means of "deconstructing" and "reconstructing" different projects into granular metrics classified as costs or benefits and further divided into cash and non-cash categories. Risk adjusted economic values based on meta-analysis and high quality peer reviewed data are assigned to those elements of cost and benefit that can be credibility assessed in economic terms. To compensate for uncertainty with some elements of value, Monte Carlo simulations are run to test large number of outcome scenarios. Discounted net present value outputs are reported on a multiple account basis to identify stakeholder outcomes. The same results are mapped to Envision categories to show which planning and design decisions contribute to value associated with the projects. When bundling projects, institutional investors will examine BCE based project business cases (stated in the risk adjusted monetary units) and Envision sustainability ratings. As a result, they will find themselves considering the credibility of projects and the value of their associated outcomes as opposed to the type, location, or size of facility as they assemble bundles of disparate projects to reach financing goals.

CAPACITY: Which Projects ARE Green and What Will They Deliver?

Who is saying which projects are "Green" and what they will deliver? The Green Bond market has revealed a rapidly growing demand for professionals and organizations with the capacity to formally opine on specific investments, made largely by private or corporate entities. Accounting firms and financially oriented consultancies are doing their best to fill the demand.

In the public sector, competition for resources within merit based funding and other programs is leading to capacity needs within the governing/administering agencies. Often, they are relying on infrastructure delivery professionals to screen projects for funding, however, in cases involving some form of public private partnerships, the accountants, consultancies, and lawyers are beginning to play leading roles.

Infrastructure and Building Specialists

As attention is turning to the role of infrastructure and building projects in green portfolios, accounting firms and consultancies are moving to provide capacity yet, infrastructure projects are complex and require depth of knowledge and experience in planning, design, construction, and operations. In addition, most projects are subject to extensive scientific, environmental, economic assessment as well as stakeholder outreach. There are very few accounting firms or consultancies equipped to opine with credibility on infrastructure and building projects. On the other hand, the infrastructure delivery industry including

© ASCE 2014

professionally licensed/registered/certified planners, engineers, architects, program managers and constructors understand every facet of project performance. They are the first professionals to be associated with infrastructure and building projects and are generally the last to separate. They advise project sponsors and regulators, they are responsible for environmental assessment and permitting, and they provide independent third party reviews, performance monitoring, reporting, bond feasibility opinions, LEED and Envision ratings. In each role they are guided by standards. When it comes to opining on "green" projects they, like the accountants and consultancies are navigating through large numbers of competing tools that vary in scope and are often proprietary which make them expensive. The combination of Envision with the BCE provide the objective, transparent, comparable and consistent tools these professionals need in order to take their places in project screening, certification, investment prioritization, performance measurement, monitoring and reporting.

Where is the AEC Professional Community?

There is sufficient organized capacity among infrastructure delivery professionals to advise the impact investment community now. Yet, there is little movement towards this role. It is difficult to determine whether there is a lack of awareness within finance circles or a lack of interest from the project delivery industry in filling the capacity gap. Once again, using TIGER as the example, planning and design professionals learned that their input could make the difference between a win or, a loss. Those that won tended to use tools that now inform Envision and the BCE. Round after round of TIGER has shown a growing awareness of what it takes to prepare comprehensive, articulate and competitive applications. Those applications will have a great deal in common with the due diligence process which can begin at concept level and continue through years of post commissioning performance monitoring and reporting. As the infrastructure delivery community learns (sometimes the hard way) that Envision can guide them through sustainable design and the BCE can enable them to reveal project value. Used in combination, the infrastructure delivery professional can better address and inform stakeholder interests. The reward for filling the capacity gap includes enhanced competitiveness, greater financial, economic, social and environmental returns; more resilient communities; time savings and access to new opportunities.

CONCLUSION

© ASCE 2014

THERE IS A NEW GAME IN TOWN. It involves intense competition for resources. Winning requires skill, experience, the right tools and rules to govern the game. Adding third and fourth dimensions to Envision: economics and risk assessment will enable players to enter the world of project funding and finance. It will place infrastructure delivery professionals at the center of project packaging and prioritization. Most importantly, it will provide the credibility, scale, and needed affordability to set the stage for mass deployment – all ingredients required to address the standardization and capacity challenge.

© ASCE 2014

Sustainable Infrastructure - From Business Case to Investment

By Martin Janowitz, MES, ENV SP. Vice President Sustainable Development, Stantec Consulting

Abstract

Civil infrastructure in both the United States and Canada is in distress. Trillions of dollars of investment is needed by 2020 to address deterioration, strained capacity, and underperformance. Conventional methods must be replaced by a new holistic approach that not only addresses the social, environmental, and economic impacts of infrastructure but demonstrates how developing sustainably creates value, mitigates risk and warrants investment. The Envision™ rating system and related business case analytic tools are helping inform defensible design decisions, evaluate relative sustainability, and recognize success to assist in closing the infrastructure gap in a way that is both financially and environmentally prudent and far-sighted.

Today's Civil Infrastructure

Those of us who work in the realm of civil infrastructure have known for some time what is becoming obvious to the average North American citizen - the public infrastructure that enables our society and economy to function is in deep distress literally to its very foundation. Infrastructure is indeed the foundation that connects the nation's businesses, communities, and people, driving our economy and improving our quality of life. But today, capacities are strained and facilities are deteriorating at an alarming rate. Despite notable bright spots, the overall pattern of decline extends to transit, bridges, highways, energy, and environmental infrastructure as well as social infrastructure including healthcare, education and public buildings. Bottom line – this infrastructure is no longer providing the levels of performance or competitive advantage we have long relied upon. This has reached a critical juncture just as we experience a perfect storm - a deteriorating patchwork of physical and social infrastructure, ever scarcer and debilitated natural resources, growing community demands for quality of life attributes, and a wave of natural calamities that have actualized the risks and effects of climate change.

It is generally agreed that infrastructure renewal would provide short and longer term social and economic benefits both within their home regions and as a catalyst for success in export industries that must capitalize on every competitive difference within global markets. For an economy to be in the first tier of competitiveness, it needs a first class infrastructure system – transport systems that move goods and people efficiently and at reasonable cost by land, air and water; transmission systems that deliver reliable, cost-competitive power from a range of energy sources; and water systems that drive industrial processes as well as daily domestic functions. Yet today, our infrastructure systems are failing to meet these expectations just as investment in infrastructure is faltering as governments seem primarily preoccupied by a strain of staunch fiscal conservatism that sees every

© ASCE 2014

investment as an expense and every government initiative as an inappropriate imposition. With each year of neglect, the problem grows worse.

According to the American Society of Civil Engineers' 2013 Report Card for America's Infrastructure (a comprehensive assessment every four years of the nation's major infrastructure categories) , investments of more than $3.6 trillion are needed by 2020 to reverse the decline and remedy the insufficiencies of public infrastructure. At least $1.6 trillion of this amount is as yet unfunded. The Report indicated that America's cumulative point average for infrastructure was judged a "D+", ranging from a high of B- for solid waste to a low of D- for inland waterways and levees. The proposed investment would advance American infrastructure to a "B". In Canada the situation is much the same. The non-partisan 2012 Canadian Infrastructure Report Card presented that a significant amount of the four major infrastructure asset categories for municipal infrastructure ranked between "fair" and "very poor". The replacement cost of these assets alone was estimated to total $171.8 billion nationally.

But even if we found the resources to respond to the problem adequately, most of us also know that the real challenge won't be solved merely by replacement or even additions to conventional infrastructure. In an era characterized by resource and carbon constraints, and by a growing array of social and demographic pressures, our infrastructure needs be designed and integrated in ever more efficient and responsive ways. The very basis of our conventional approaches to infrastructure planning, design and operation must therefore be subject to critical examination and change.

On the plus side, this process is already substantively underway through the rapidly evolving and accepted integrated sustainable infrastructure 'movement'. This has arisen out of growing interest and sensitivity to patterns of urban sustainability wherein planners and engineers have largely accepted the principle of avoiding, minimizing or mitigating the adverse environmental and social effects of human works. This perspective takes into consideration aspects such as localized resource or energy efficiencies, increased use of recycled or reusable materials, better contaminant containment and treatment, and other environmental and resource management enhancements. There is also growing recognition that individual infrastructure components cannot be thought of as isolated, passive, single function resources. Rather, they play an active and interactive role (intentionally or unintentionally) in shaping and influencing broader characteristics of society amidst a dynamic pattern of interrelationships.

With these characteristics in mind the evolving changes to infrastructure planning and design are increasingly considering their effect on overall community futures and applying innovative design solutions to optimize community benefits. As a consequence there is already a growing roster of creative yet practical examples of

© ASCE 2014

the application of the principles of sustainability in infrastructure that are already making a difference in the communities they serve. This approach encourages comprehensive, integrated infrastructure planning and design that accepts the premise that there are inevitable, inextricable and multiple interactions and potential connections between the infrastructure systems of energy, waste, water, transportation, landscape, information and food. Even recognizing this, it is difficult to move beyond tinkering, adjusting design and performance towards resource and energy efficiency while adding accommodations to social concerns. But more substantial and holistic planning, design and management changes are not going to evolve unless owners and engineers embrace them as sensible solutions from both a values and value points of view. It is essential therefore to focus on the value proposition which must be clearly understood and brought to bear if truly sustainable infrastructure systems are going to become the norm.

The most innovative sustainability oriented projects are being implemented because they demonstrate value to the core constituencies who need to support them – governments, financiers, environmental and social interests and communities. To achieve more widespread adoption we must therefore be more clearly focused on the ways sustainability can create value. Only then are we are more likely to both conceive and realize infrastructure systems that exemplify those values. It will also be important to fairly compare and evaluate relative triple bottom line performance and return on investment, so that we can establish new benchmarks, compare project options, gauge progress and recognize superior systems and outcomes. To those ends there has been significant evolution of economic and value oriented analytic tools and frameworks. Beyond enhancing our ability to make and defend choices the availability and acceptance of such tools also opens the door to important new vehicles for infrastructure financing, and infrastructure asset management.

The starting point has been to firmly establish that the essence of sustainability is a focus on holistic benefit. Holistic approaches by necessity require project benefits to be broadly distributed locally and globally, over both short and long term. Projects must also cover the spectrum of environmental, social and economic gains. This contrasts with conventional notions of infrastructure value – which over the last century have largely been about delivering a specific, discrete service at the lowest upfront capital cost. While this approach delivered the largest quantity of infrastructure for dollars spent, it ignored a number of critical elements; which cumulatively contributed to many of the infrastructure deficiencies and environmental and social challenges that we are facing today. This conventional approach has resulted in an array of relatively isolated projects which essentially divorced the individual project from an inclusive view of their place and impact within the wider infrastructure system. These projects often pay minimal attention to infrastructure impacts in relation to other infrastructure components and to the communities within which the project was to be built. The pattern has been to build

© ASCE 2014

projects with a singular focus - a water or waste water treatment facility to provide water or deal with sewage; a highway or roadway to move people and goods; or a landfill to dispose of waste. Of course each infrastructure component must accomplish its primary task well, but if we only focus on the explicit job we typically will not adequately consider broader environmental, socio-economic or aesthetic effects or opportunities.

When RFPs are asking only for specified infrastructure deliverables there has also been almost no incentive for designers to propose additional budget resources for broader systemic evaluations. This is the case even though a thoughtful sustainability perspective recognizes that civil infrastructure is inherently systemic. Taking this view, it should become obvious that one system is not divorced from the rest. For example, our transportation systems are inextricably bound to our land use frameworks, which provide the structure for siting our water and waste facilities that in turn impact those same transportation systems. Our energy systems are also typically large users of water and conversely some water systems require significant energy inputs. Ultimately, the overall quality of life and health in our communities will be inordinately affected for better or worse by the performance and attributes of the web of infrastructure components. There is therefore considerable value to society in raising the standard of integrative, systemic design and planning.

In our sector (engineering-architecture-planning), there is a longstanding truism that proposing to design towards innovative lifecycle efficiencies has been an almost sure fire way to gain admiration while losing the competition. This reflects the over emphasis on front end over lifecycle cost, though this focus was perhaps inevitable in an era when the responsibility for infrastructure operation has been largely disconnected from the responsibility for design and construction. An over-emphasis on front end cost does not incentivize operational efficiency, longevity or resilience, all of which contributes to greater overall resource, energy and cost efficiency. Seeking to honor sustainability principles on the other hand provide an incentive to design towards full lifecycle project value. Optimizing these efficiencies is sensible stewardship for both the environment and the public purse.

This means asking and answering a significantly more comprehensive set of questions that seriously consider topics as diverse as:

- How will a facility or operation affect or impose on its neighboring community? Can the project be a force for community cohesion rather than separation?
- What are the aesthetic, lifestyle or health effects or aftereffects of a project from inception to decommissioning?
- Are there potential synergies from interactions between seemingly unrelated infrastructure components?
- How will the project influence settlement patterns?
- Can the project contribute to active transportation options?

© ASCE 2014

- How will the project contribute to emissions and specifically to climate change? Can the project contribute positively? Will it enhance resilience and adaptive capacity?
- Are social equity issues being addressed as a precursor to siting decisions?

Beyond technical design or planning improvements a sustainability oriented view also pays close attention to process, especially with regard to stakeholder engagement. While infrastructure may generally reside beneath the consciousness of most citizens, in recent decades, stakeholders and citizens have increasingly been active protagonists around infrastructure-related controversies and in general have greater interest and expectation of being engaged around decisions that affect their community lives. At the first level this has led to a general standard that incorporates stakeholder communication and consultation. Beyond that we are moving to the point where stakeholders are occasionally if not regularly considered constructive collaborators or even 'partners'. This synergy can actually contribute to better projects and practices and to only undertaking the right projects. A healthy pattern of citizen participation also benefits communities in a number of ways that go beyond the scope of any specific project – building community cohesion, trust in governance and often more meaningful long term community vision and priorities. Citizen engagement is therefore not an aside but a central component of a genuine sustainable infrastructure initiative.

The Envision™ Rating System

All of these aspects point to planning frameworks that explicitly consider the optimal value for the community as a whole and identify effects that would negatively impact other parts of the system. By broadly valuing 'quality of life' impacts, any infrastructure component can intentionally contribute to community 'goods' beyond the specific service provided. Comparing options and making choices that balance project specific and broader community values and objectives cannot however be easily accomplished through ad hoc or one off processes. This was clearly understood by the three major U.S. associations – the American Public Works Association, the American Council of Engineering Companies and the American Society of Civil Engineers when they set out to develop a common and consistent framework for evaluating and comparing all types of civil infrastructure through their creation, the Institute for Sustainable Infrastructure. Their effort gathered further momentum when it joined in a collaborative partnership with the Zofnass Program for Sustainable Infrastructure at the Harvard Graduate School of Design. Thus the pioneering Envision™ Rating System for Sustainable Infrastructure came to fruition in 2012. Now becoming well known across United States, and gaining attention in Latin America, Canada and beyond, Envision is rapidly establishing a new, common basis to evaluate and make defensible design choices, to evaluate the relative sustainability of comparable projects and to identify leading examples for recognition. Envision systematically poses a comprehensive set of questions tied to

© ASCE 2014

explicit evaluation criteria to identify the sustainable values embodied within projects.

Equally significantly, the growing application of Envision and the emergence of synchronized holistic 'triple bottom line' and 'sustainable return on investment' analytic tools also challenge planning and design teams to create solutions that deliver for maximum social, environmental and economic impact. They provide a sensible basis to assess risk, cost-benefit and investment parameters of various alternatives. Such analysis creates a firmer ground for decision-makers and highlights a host of other ways in which these sustainability-oriented projects have added or could add genuine value to their stakeholders. These business cases can guide designers to outcomes that deliver the greatest overall "bang" for the buck over project lifecycles while simultaneously helping to identify and respond to the interests of project stakeholders.

These analyses are not only applicable at the early design stages but can be used post-construction to evaluate the success of completed projects and to be at the center of robust asset management frameworks. In the case of previously completed projects, the application of Envision and its companion business case analytic tools helps focus on what can be learned and improved on similar future projects. Whether during design or post completion, some of these value-added elements include:

Stimulating growth and development
Developing local skills and capabilities
Improving community mobility and access
Enhancing public space
Preserving historic and cultural resources, views and local character
Fostering collaboration and teamwork, and stakeholder engagement
Identifying by-product synergies between systems
Diverting waste from landfills
Reducing energy consumption
Preserving prime farmland and greenfields
Controlling invasive species
Preparing for long-term adaptability (to climate and other risks), and
Extending useful life

These are not abstract benefits. They each provide a mix of authentic social and environmental outcomes, and just as importantly, they result in measurable direct or indirect economic value through cost savings, revenue gains, economic development, and enhanced community health and desirability.
In some cases the effect of infrastructure changes or development can go well beyond achieving higher performance projects rising to be truly transformational within their host communities or regions. There is a growing roster of important

© ASCE 2014

cases of projects that are playing key roles in transforming their communities by becoming linchpins in much more substantial community development and enhancement. Such examples include remarkable urban revitalization scenarios, brownfield rejuvenations, and extension of basic quality of life services and ancillary benefits to remote or under-served regions.

While not yet mature, another potential value in sustainable infrastructure projects is related to financing. This is a sphere of growing interest and sophistication as government or agency project owners wrestle with decreased access to capital resources from traditional sources just as the need for investment is so acute. In the old world order, infrastructure owners made choices considering priorities, borrowing capacity and tax-based revenues, often building what could get funded or just part of what was needed for lowest front-end cost. Municipalities lined up for formula grants from infrastructure funding pots, working their political connections to be the 'lucky' recipient. While this pattern was never ideal it allowed municipalities and states or provinces to get by when the overall state of infrastructure assets was relatively young and serviceable. But now our infrastructure requires massive upgrade just when municipal and state/provincial governments are woefully under-resourced to directly fund renewal capital. The few formula funding pots have either disappeared or have become increasingly difficult to access and new merit funding opportunities such as the $4.18B TIGER Grant Program generated thousands of applications resulting in more than $50B in demand. At this critical juncture when shortcomings in infrastructure could leave them in significant jeopardy, the traditional sources of public funding are wholly inadequate and cash-strapped communities, counties or regions must now compete globally in a nearly desperate race to attract and out-compete their cousins for capital.

Against this setting infrastructure owners have been hoping that the private sector, and especially so called impact investors, will step in to fill the investment gap. Impact investors include institutions (such as pension and community investment funds), philanthropic trusts, and investing funds primarily distinguished by their intention to address social and environmental challenges through their deployment of capital – making this class of investors perfect candidates to respond to the parameters of sustainable infrastructure. This however raises the question, "how attractive is public infrastructure as a destination for impact and other forms of private capital"? On the one hand, public infrastructure, if properly managed and maintained, offers a stable and visible long term asset with a steady user base and well known, potentially growing, inflation protectable revenue streams. But these attributes are counter balanced by obstacles. Impact or other private investors are seeking opportunities within the $53 trillion global infrastructure sector for the $26 trillion in capital they control and many have a hunger to place capital in public infrastructure, but the relatively small project size, long lead time, political risk and due diligence costs associated with these projects are keeping them away. In simple

© ASCE 2014

terms, they have struggled with quantifying the value and risk associated with specific projects and assembling portfolios of projects large enough to distribute those risks. Large constructor-operators able to participate in public private partnerships (P3) are also looking for opportunities that can meet their risk profiles and need for scale through projects that can be bundled.

The suite of tools – Envision and sustainable business case analytics – will over time become invaluable in addressing these concerns and opportunities by transforming the way projects are developed, vetted and positioned for financing, by evaluating sustainable return on investment, assessing risk adjusted value, and providing comparability among disparate projects. These consistent frameworks will challenge sponsors to make a transparent case for funding, as investors realize that much of the value they seek exists but has heretofore not been accessible. By revealing answers to some of the questions posed in this approach, it will not be long before vetting based on transparent and objective business cases becomes standard practice. Project sponsors who understand and articulate the full value and risk associated with their projects will realize an advantage in the competition for merit funding and impact capital. Realizing the value of sustainability in the realm of capital financing thus may be the final important piece of the sustainable infrastructure value proposition.

Over time, as comprehensive business cases become more common, users will realize additional benefits as projects are regionally bundled and systems are managed on a basis of value for money, defining opportunities that deliver reasonable returns at reasonable risk as compared to other investment options. Infrastructure projects can provide long-term predicable returns, inflation protection, and positive social and environmental impact. With these factors rapidly coalescing, the stage is set for the new sources of private impact capital to step up and fill a role formerly played exclusively by public funding sources.

The case for sustainable infrastructure is rapidly maturing from theory to practice. Recent Envision awards highlight both progress to date and opportunities yet to be realized. The benefits to societies worldwide have been spurred on by the early successful example projects. These examples demonstrate that sustainable performance of infrastructure can be the backbone of the operation and development of communities that are moving towards vitality and holistic genuine progress. These infrastructure systems are positively affecting the renewable availability and allocation of resources, community health and quality of life, social conditions and surrounding natural integrity. In an era when we increasingly appreciate the imperative of communities and societies that feature these attributes in stable, resilient and adaptable patterns, the priority for sustainable infrastructure has never been more apparent.

© ASCE 2014

Conclusion:

There are solutions and new methods for addressing the future of United States and Canadian infrastructure that account for financial and environment impacts. The Envision™ rating system, particularly complemented by increasingly refined and practical business case analytic tools, is helping meet this need by providing a consistent framework by which the environmental, social, and economic value of infrastructure can be presented to owners, investors, and impacted communities.

References:

"2013 Report Card for America's Infrastructure." *American Society for Civil Engineers,* http://www.infrastructurereportcard.org/a/#p/home>(July 14, 2014).

"2012 Report Card for Canadian Infrastructure." *Canadian Infrastructure Report Card,* http://www.canadainfrastructure.ca/en/report.html>(July 14, 2014).

Author Contact Information:
Martin Janowitz MES; ENV SP, Envision Verifier and Trainer
Stantec Consulting
40 Highfield Park Drive
Dartmouth Nova Scotia B3A 0A3; Canada
902-468-0406 Direct; 902-499-8069 Cell; 902-468-9009 Fax
marty.janowitz@stantec.com

© ASCE 2014

Life Cycle Analysis of Municipal Solid Waste (MSW) Land Disposal options in Bangalore city

G.L. Sivakumar Babu[1] P. Lakshmikanthan[2] and L.G.Santhosh[3]

[1]Professor, Dept. of Civil Engineering, Indian Institute of Science (IISc), Bangalore, Karnataka-560012. E-mail: glsivakumar@gmail.com, Phone: +91 80 2293 3124
[2]Research scholar, Centre for Sustainable Technologies, Indian Institute of Science (IISc), Bangalore, Karnataka-560012. E-mail: lakshmikanth@astra.iisc.ernet.in
Ph: +91-9036406364
[3]Research Scholar, Center for Sustainable Technologies, Indian Institute of Science (IISc), Bangalore, Karnataka -560 012, INDIA, Mob: +91-9611187003, E-mail: lgsanthu2006@gmail.com

ABSTRACT

Landfills are common land disposal methods employed in most of the developing countries across the world. The waste disposal methods such as open dumps, landfill without and with gas recovery systems and bioreactor landfills are assessed using Life cycle analysis (LCA) method. These scenarios were applied to Bangalore (Karnataka, India). This method serves as a decision making tool for selecting the most sustainable, energy and cost efficient methods. The analysis is done in terms of the material flow, energy flow and impacts of open dumping and land filling on the environment. The global warming potential was considered as most important factor as its impact on the environment is high. The life cycle cost analysis (LCCA) is also done considering an average life of a landfill as 50 years. Cost analysis was done in terms of the initial fixed costs, yearly maintenance cost and post closure monitoring and maintenance cost. The revenue generated from trading power that could be generated from the landfills was also considered. The power that could be generated from the landfills was calculated as 11MW. The bioreactor landfill could be used twice in 50 years when compared to the engineered landfill as the waste stabilisation period varied from 10 years in bioreactor landfill to few decades in case of engineered landfills. Among the four scenarios the bio reactor landfill had an edge over the other methods environmentally and economically, whereas the open dump scenario was the least favoured option as the impacts caused due to it on the environment was considerably huge.

1. INTRODUCTION

Bangalore city, one among the eight metros in India, produces about 4500 tons per day (tpd) of municipal solid wastes (MSW). A major constituent (72%) of this is organic waste (Chanakya et al 2010). The transportation and disposal of waste is undertaken by the local municipal authority Bruhat Bengaluru Mahanagara Palike (BBMP). All the wastes are taken to the landfills situated on the outskirts of Bangalore. Currently all the landfills situated in Bangalore have reached their capacity and are receiving waste in excess of their capacities. It has been reported

© ASCE 2014

that till recently, about 60% of the MSW collected was dumped at about 60 known and unknown (unrecorded) dumping sites around Bangalore. Further, among these more than 35 sites received a mixture of domestic and industrial waste (Lakshmikantha, 2006). Under such circumstances it is important to analyse the various land disposal options using Life cycle analysis (LCA). LCA serves as decision making tool in selection of the most sustainable, economic and environment friendly land disposal options. In this paper four land disposal options are considered which are analysed using the LCA method. The four scenarios considered for the study are given below.

Scenario 1: Open dumps
Scenario 2: Landfill system without gas recovery
Scenario 3: Landfill system with gas recovery
Scenario 4: Bioreactor Landfill system

The best option in terms of minimal environmental consequences and costs is selected by comparing the impacts caused by each disposal method.

2. LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) is a tool to quantify environmental burdens associated with products or activities throughout their life cycle, or “from cradle to grave” (Finnveden, 1999; Denison 1996 and Kasai, 1999). LCA as a tool was applied to industrial products initially and developed rapidly during the 1990s. LCA studied the overall environmental burdens generated by products, processes or activities during their entire life cycle, which include extraction and processing of raw materials, manufacturing, production and maintenance, packaging, transportation and distribution and recycling (ISO, 1997). LCA has been used extensively to evaluate solid waste management systems as well as for comparison of different scenarios for integrated waste management systems (Moberg et al, 2005; Mendes et al, 2004). The methodological framework used in this paper is the LCA as defined by ISO standards (International Standard Organization, ISO 14040:14043). The general categories of environmental impacts considered include resource use, human health and ecological groups. There are four phases for LCA, which include:

1. Goal definition and scoping
2. Inventory analysis
3. Assessment of potential environmental impacts
4. Interpretation or improvement analysis.

An inventory of energy requirements and selected environmental emissions is performed by analysing the materials and energy flow in and out of the systems. Though the focus is mainly on environmental consequences and energy use, other impact categories such as acidification, eutrophication, photochemical ozone creation potential (POCP), human and ecotoxicological impacts and operation and maintenance costs are also considered. The negative environmental consequences from the landfill can be more significantly studied and analysed using the LCA tool. The various inputs such as municipal solid waste (MSW), cover layers including geomembranes and geotextiles, energy (fuel), raw materials like soil and vegetation cover and water are considered. The environmental impacts are assessed in terms of the pollution to ground and water, gas emission to the atmosphere (mainly CH_4 and NO_2) and the impact on the human population.

3. GOAL DEFINITION AND SCOPING

The present LCA study is performed by carrying out an inventory of the inputs and outputs related to land filling methods in Bangalore. In this study the MSW, the raw materials needed for cover systems, energy in terms of fuel required for transporting the MSW from source to the landfill site and moisture required are considered as inputs to the system. The outputs are emissions to the air and water and the energy that can be recovered from the landfills. Four scenarios are being considered and the boundaries of each system are defined. The LCA boundaries were limited to the landfill site situated in Bangalore. The calculations were done based on the present population of Bangalore (census 2011) and the waste generation rate of 0.6kg/capita/day (Chanakya et al, 2009). Bangalore's MSW is typical in terms of its organic content as it consists of more than 70% organic content (Chanakya et al, 2009). The amount of MSW generated per capita is estimated to increase at a rate of 1–1.33% annually (Pappu et al, 2007; Shekdar, 1999 and Bhide and Shekdar, 1998). The considered scenario consists of three main steps: collection, transport and land filling of MSW. Therefore the emissions due to transportation of vehicles are also considered in the analysis.

Scenario 1: Open dumps

The open dumps are places which do not have any liner systems installed and the area is temporarily or permanently used as waste disposal sites. There is no initial costs incurred in this method but the environmental consequences are very high as the leachate may pollute the soil and ground water and the emissions could pollute the air. The boundary in this case is the area of the dump site and only the transportation charges apply. Compaction and levelling are seldom done at the site. Figure 1 shows the system boundary.

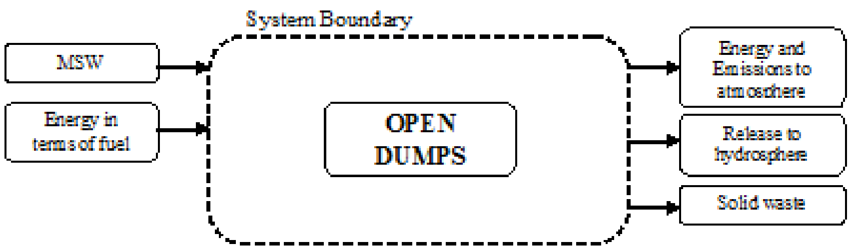


Figure 1. System Boundary of open dump

Scenario 2: Landfill system without gas recovery

This method satisfies the requirements of an engineered landfill but does not have the gas recovery system. The waste is dumped on the land which has the protective liner system and closed using the cover system. The waste undergoes anaerobic degradation and releases landfill gas (LFG) to the atmosphere. The quantity of release of LFG depends on the quantity of degradable organic content

© ASCE 2014

present in the waste. The LFG contains methane and carbon-di-oxide as its major constituents and traces of HCl, H_2S and HF. The CO_2 released is not accounted for in the global warming potential (GWP). Since there is no gas recovery system installed these gases are emitted into the atmosphere. Some of these gases like methane are green house gases and lead to global warming. There is also a release to the hydrosphere in the form of leachate which is controlled by the liner system and the leachate collection and treatment systems. Figure 2 shows the system boundary of the scenario 2.

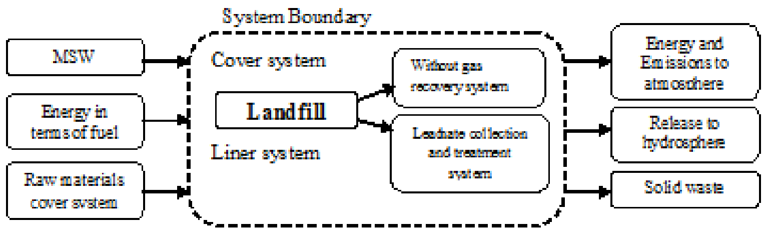


Figure 2. System Boundary of landfill without gas recovery system

Scenario 3: Landfill system with gas recovery

This scenario is similar to that of scenario 2 but has the gas recovery system. The LFG generated is captured efficiently by the gas collection system and later on this can be converted into a useful form of energy. This set up already has the leachate collection and treatment system. Power can be generated by the LFG to electricity conversion plants. Periodic monitoring and maintenance is done post closure of the landfill for 30-40 years until the waste inside the landfill is stabilized.

Scenario 4: Bioreactor Landfill system

A bioreactor landfill changes the aim of land filling from the storage of waste to the treatment of waste. A bioreactor landfill is a system that enhances the degradation of refuse by microbial action. Microbial degradation may be promoted by adding certain elements (nutrients, oxygen, or moisture) and controlling other elements (such as temperature or pH). The most widely used and understood method of creating a landfill bioreactor is the recirculation of leachate, as the factor that limits microbial activity in a landfill is water. The recirculation of leachate increases the moisture content of the refuse in the landfill and, therefore, promotes waste degradation. The boundary of this scenario is similar to that of the scenario 2. There is a provision for leachate recirculation and landfill gas collection.

4. INVENTORY ANALYSIS

4.1 Input analysis

Energy inputs are those that are derived from non-renewable sources (diesel). The fuel that is required for transportation and management of waste, electricity needed for operation and maintenance, cover systems and liner systems, leachate collection and treatment system and gas collection and conversion systems are considered inputs to the system. The first scenario does not include all these things

© ASCE 2014

except the land. In this study the concentration would be mainly on the inputs that pose severe threat to the environment through releases to the atmosphere and hydrosphere. Energy consumed for the transportation of wastes to the landfill from the generation places is calculated by considering three mean distances 10, 20 and 30 kms from the disposal site. The density of the waste in the compacted trucks is considered as 425 kg/m ^{3} and each compacted truck has a capacity of 6 tonnes of MSW. Assuming an efficiency of the trucks as 3km per litre of diesel and the energy content of diesel as 36.7MJ/L the energy required for the transportation of MSW through the three mean distances is given in table 1.

Table 1. Energy required for transportation of MSW for the three considered mean distances

Distance in km	Distance (to and fro) in km	Energy required in MJ/tonne
10	20	42.8
20	40	85.6
30	60	122

Energy consumed for the management of MSW in the landfill site is calculated by assuming the capacity of the landfill as 2090000 tonnes/year (based on 2011 population and generation rate of 0.6kg/capita/day), four machines working in situ (two bull dozers and two roller compactors) and the diesel consumption of 15 Litres/hour. Assuming the working hours per day as 8h/day and 300 days/year, the energy consumed was calculated as 3 MJ/tonne of MSW. Table 2 summarises the total inputs to the disposal system.

Table 2. Inputs to the landfill system

Parameters	Values
Quantity of MSW	13.8×10^6 tonnes of MSW (for 25 years, design is done according to CPHEEO manual 2000)
Volume of daily cover	0.1% of Volume of waste (1.909×10^6 tonnes of MSW) (for 25 years, design is done according to CPHEEO manual 2000)
Volume of cover system	0.08% of Volume of waste (1.5×10^6 tonnes) (for 25 years, design is done according to CPHEEO manual 2000)
Total average rainfall in Bangalore	931 mm/year (based on 100 year data, Indian Meteorological Department)
Energy in terms of fuel	125 MJ/Tonne of MSW(3 litres of Diesel/Tonne of MSW)

© ASCE 2014

4.2 Output analysis

The outputs of the landfill systems are in the form of landfill gas that is generated by the decomposition of MSW, the leachate that is being generated and finally the left over inert waste that can be used as compost. Also the emissions from the trucks and bulldozers that are used for transportation and management of MWS are considered as outputs from the system. The quantity of landfill gas that would be generated after 15 years by assuming the values given in table 3 (assuming only 40% of the total waste generated is land filled and has around 90% of degradable organic content) was calculated as 4.49×10^{12} Litres from 13.8×10^{6} tonnes of MSW and 815000 Litres of biogas per tonne of MSW using the Buswell & Mueller equation. According to this relation, the methane fraction from degradation of glucose is given by

$$C_6H_{12}O_6 \rightarrow 3\ CH_4 + 3CO_2$$

This equation is considered in order to calculate the maximum emissions from the waste. It was assumed that the landfill gas contained 50% methane and 50% carbon-di-oxide. For the landfill systems with gas recovery system, there is energy savings associated with the conversion of the landfill gas (LFG) to electrical energy.

Road transport emits mainly CO_2, NO_x, CO and NMVOCs; however it is also a small source of N_2O, CH_4 and NH_3. Therefore the only major direct greenhouse gas emission is CO_2. Emissions of CO_2 are directly related to the amount of fuel used. The kilometre travelled-based CO, HC, NO_x and $PM_{2.5}$ Emission Factors of emission control technology Euro 0 Light Duty Diesel Trucks (LDDTs) are 11.95, 1.75, 2.36 and 0.62 g/km, respectively (Kebin et al 2010). The kilometre travelled-based Emission Factors of CO, HC, NO_x and $PM_{2.5}$ of Euro I Heavy Duty Diesel Trucks (HDDTs) are 4.52±2.56, 0.68±0.19, 6.32±1.58 and 0.58±0.34 g/km. The emissions calculated based on the above mentioned values for the transportation and the management of MSW is given table 3.

Table 3. Diesel consumption for transportation and management of MSW

	Transportation				Management	
Parameters	**Emissions in g/L of diesel**	**Emissions g per tonne of MSW**			**Emissions in g/L of diesel**	**Emissions g per tonne of MSW**
Distance(to and fro) in km		20	40	60		
Diesel Consumption (Litres/tonne of MSW)		1.2	2.3	3.3		0.5
CO_2	2663[1]	3195.6	6124.9	8787.9	2663[1]	1331.5
CO	11.95	14.34	27.485	39.435	4.52	9.04
HC	1.75	2.1	4.025	5.775	0.68	1.36
NO_x	2.36	2.832	5.428	7.788	6.28	12.56

© ASCE 2014

$PM_{2.5}$	0.62	0.744	1.426	2.046	0.58	1.16

1= www.ec.gc.ca

The total outputs include the methane and the carbon dioxide that are released from the landfill and the gases that are emitted by the vehicles. The landfill system with and without recovery of landfill gas are given in table 4. The efficiency of the gas collection system is assumed as 80%. The transportation distance considered here is the maximum distances of 60km. Emissions for management of waste in the open dumps are considered nil as there are no management activities undertaken.

Table 4. Total emissions from the considered landfill disposal system

Emissions from the system	Open dumps	Landfill		Bioreactor landfill
	in g	With Gas Recovery in g	Without Gas Recovery in g	in g
CH_4	268950	53790	215160	53790
CO_2	289721.4	78555.9	347505	78555.9
CO	48.47	48.47	48.47	48.47
HC	7.135	7.135	7.135	7.135
NO_x	20.338	20.338	20.338	20.338
$PM_{2.5}$	3.206	3.206	3.206	3.206

The landfill leachate that is generated is released into the underlying soil and later into the groundwater. Assuming 80% precipitation in 4 months (monsoon period), peak leachate quantity (thumbrule basis) is around 200 m^3/day.

5. IMPACT ASSESSMENT

According to the life cycle characteristics of waste treatment/disposal, its environmental impacts are classified into five kinds: energy depletion potential (EDP), global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), and photochemical oxidant potential (POCP). However in this paper only energy depletion potential (EDP), global warming potential (GWP) and eutrophication potential (EP) are considered. The characterisation factors of the green house gases that are considered for calculation are given in Table 5. Transportation of MSW mainly contributes to the acidification and human toxicology impacts.

Table 5. Characterization factors based on equivalency factors from IPCC 2001 GWP for 20 years and eco-indicator 95

IPCC 2001	
Resources	**Characterisation factors**
Global Warming Potential(GWP)	
CH4	62

© ASCE 2014

CO_2	1
CO	1.57
Eco-Indicator 95	
Acidification potential (AP)	
NOx	0.7
SOx	1
NH_3	1.88
Eutrophication potential(EP)	
NOx	0.13
NH_3	0.33
Photochemical ozone creation potential (POCP)	
CH_4	0.007
Benzene	0.189
Ethene	1
Hydrocarbons,unspecified	0.398

The impacts of the respective scenarios are calculated by multiplying the equivalency factors (given in Table. 5) to the respective quantities. The equivalency factors are multiplied by the quantity of the gases released. The total impacts in disposing one tonne of waste in the four scenarios are given in table 6. The impacts presented in table 7 are sum of all the impacts from transportation and waste degradation.

Table 6. Impacts of various scenarios on environment for disposal of per ton of waste.

Impacts	**Scenario 1 (in g)**	**Scenario 2 (in g)**	**Scenario 3 (in g)**	**Scenario 4 (in g)**
Global Warming Potential (GWP) (relative to CO_2)	16674976	13339996	3335056	3335056
Acidification potential (AP) (relative to SO_2)	14.2	14.2	14.2	14.2
Eutrophication potential(EP) (relative to NO_3)	2.6	2.6	2.6	2.6
Photochemical ozone creation potential (POCP)	1885.4	1508.9	379.3	379.3

Scenario 1 projects the maximum environmental consequences. This reason for this is the absence of the liner system, gas recovery system and the leachate collection and treatment system. The GWP and POCP are maximum in this case and therefore severely affect the environment. Therefore this is the least considered option in terms of environmental consequences. Among the landfill systems the Scenario 4 (bioreactor landfill) emerges to be the best option. The global warming potential and Photochemical ozone creation potential (POCP) are the minimum. Though the engineered landfill system is similar to the bioreactor, the various advantages of bioreactor landfills put it ahead of scenario 3. The advantages of

© ASCE 2014

bioreactor landfills described by Warith (2002) are (1) Enhancement in the LFG generation rates (2) Reduce environmental impacts (3) Production of end product that does not need landfilling (4) Overall reduction of landfilling cost (5) Reduction of leachate treatment capital and operating cost (6) Reduction in post-closure care, maintenance and risk.

6. LIFE CYCLE COST ANALYSIS

Life Cycle Costing (LCC) is a tool or technique that enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational and asset replacement cost. Life Cycle Cost Analysis (LCCA) is a technique used to evaluate the economic consequences over a period of time of mutually exclusive project alternatives. LCCA was applied to equipments initially. The understanding and uses of this tool have improved immensely and it is being applied to various fields, products and processes. In this study the costs considered are the direct costs (initial costs and operation and maintenance costs). The cost details given in the manual developed by the Central Public Health and Environmental Engineering Organisation (CPHEEO) have been used in this analysis. The costs are summarized in table 7.

Table 7. Cost details for a landfill

Sl.No	Item	Cost Rs x 10^5
1	**Initial Fixed Cost**	
	Site Selection and Site Characterisation Cost	26.88
	Design and Detailed Engineering Cost	17.50
	Site Development Cost	160.30
	Total	**204.68**
2	**Yearly Running Cost (Active)**	
	Phase Development Cost	427.25
	Phase Operation Cost	164.75
	Phase Closure Cost	175.95
	Total	**737.95**
3	**Yearly Running Cost (Post Closure)**	
	Post Closure Care Cost	37.00
	Total	**37.00**
	Total	**979.63**

Note: All the above mentioned prices are of base year 1998 as given in the CPHEEO manual 2000.

The above cost does not include gas recovery system. The first two scenarios do not include the gas recovery system whereas scenarios 3 and 4 include the gas recovery system. Capital costs vary according to the type of plant used to process the methane. California's capital costs varied from $606 per kW to $6,811 per kW in 2001(California Energy Commission, Landfill Gas-to-Energy Potential in California, p. 13.). It is assumed that the cost of 1 MW plant is Rs. 333x10^5.

© ASCE 2014

The total gas generated is calculated by using the IPCC first order decay method. Bangalore generates 4602 ton/day of waste. Assuming the collection efficiency as 80%, waste generation as 0.6 kg/capita/day (Chanakya et al, 2009) and with present population as 9588910 (Census 2011), the methane generated over a period of 25 years is calculated as 9.5×10^6 m^3/yr. Using calorific value of methane (lowest) as 9000 kcal/m^3, energy generated in one year is computed as 358 TJ; corresponding power being 11 MW. Assuming that electricity is being sold at a price of Rs. 2 per kWh, the revenue generated due to this would be Rs. 1,98,800,000. The average life expectancy of a landfill could range from 30 to 50years. Therefore the cost analysis is done for the landfill systems for 50 years. Table 8 gives the cost and saving details of the four considered scenarios over a period of 50 years.

Table 8. Total cost details of the considered scenarios over a period of 50 years

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Initial Fixed Cost (Rs x 10^5)		204.68	204.68	204.68
Yearly Running Cost (Active) (Rs x 10^5)	-	737.95	737.95	737.95
Yearly Running Cost (Post Closure) (Rs x 10^5)	-	37	37	37
Gas Recovery system (Rs x 10^5)	-	-	333.33	333.33
Total		**979.63**	**1312.96**	**1312.96**
Cost over a period of 50 years (Rs x 10^5)	-	-	1312.96 (For a new site)	1549.9 (operation and maintenance of the same site)
Total		**979.63**	**1312.96**	**1549.9**
Total Cost over a period of 50 years (Rs x 10^5)		**1959.26**	**2625.92**	**2862.86**
Revenue generated from electricity (Rs x 10^5)	-	-	1988	1988
Cost savings over a period of 50 years (Rs x 10^5)				
Usage of the same Landfill site every 25 years for 50 years	-	-	-	204.68
Revenue generated from electricity for 50 years				3976
Total			**1988**	**6168.68**
Total savings over a period of 50 years	-	**-1959.26**	**-637.92**	**+3305.82**

Note: All the above mentioned prices are of base year 1998 as given in the CPHEEO manual 2000. The '-' sign indicates a loss and '+' sign indicates a gain/savings.

© ASCE 2014

7. RESULTS AND DISCUSSION

It is evident from table 7 that the scenario 1 is the least favoured land disposal option that can be considered as the Global Warming Potential (GWP) and Photochemical ozone creation potential (POCP) are considerably higher than the other methods. The landfill leachate generated in scenario 1 is not subjected to any treatment and is disposed off to the environment. This is an impact that can be considered in this case. Scenario 2 is better than scenario 1 but all the methane that is generated is let out to the atmosphere. Assuming 10% methane oxidation in soil, the GWP is 1333999.6 g CO_2-eq which is very high compared to scenarios 3 and 4. Scenarios 3 and 4 are similar except for the waste stabilization period that ranges from 5-10 years for bioreactor landfills to a few decades for engineered landfills. All the gases and leachate generated are collected using the gas recovery system and the leachate collection system. The GWP and POCP impacts due to scenario 1 are around 5 times and 4 times the impacts caused due to scenario 4.

The cost details show that there is a considerable amount of saving and earnings in scenario 4 over a period of 50 years. The dump sites do not incur any cost except the transportation costs but may cause immense environmental consequences. Therefore it is not considered in the cost comparison with the other systems. The absence of gas recovery system in scenario 2 keeps it out of competition. The initial fixed costs are same for scenarios 3 and 4. Additionally the gas recovery system is set for both these systems. Power is generated in scenario 3 but the stabilisation period of this system is 40-50 years, which is very high in comparison to 10-15 years in case of scenario 4. Therefore the waste in the bioreactor is stabilized at a faster rate than the engineered landfill. The additional costs that are incurred in scenario 3 are due to the need for selecting, developing new landfill sites for every 25-30 years. Whereas in Scenario 4 the existing landfill site can be mined every 25-30 years and used again. This reduces the overall costs for scenario 4.

7. CONCLUSIONS

The scenarios can be put in a descending order scenario 1 > scenario 2 > scenario 3 > scenario 4 according to their impacts on environment. The bioreactor landfill option proves to be the better option among the four scenarios. It is also sustainable and economically viable as it has a short stabilization period as compared to the engineered landfills and the money can be recovered within in a period of 50 years. It can process waste at a faster rate and also produce energy in the form of landfill gas. The scenarios can be put in a descending order scenario 2 > scenario 3 > scenario 4 according to the costs incurred. The bioreactor landfill can also generate revenue of around Rs 3,30,582,000 over a period of 50 years. Therefore the bioreactor option is the best land disposal option that can be considered for Bangalore city. The other MSW treatment options like composting, refused derived fuel and incineration require further research.

8. REFERENCES

Bhide, A. D., & Shekdar, A. B. (1998). Solid waste management in Indian urban centers. International Solid Waste Association Times (ISWA), 1, 26-28.

© ASCE 2014

Central Public Health, & Environmental Engineering Organisation (India). (2000). Manual on municipal solid waste management. Central Public Health and Environmental Engineering Orgnisation, Ministry of Urban Development, Govt. of India.

Chanakya,H.N., Shwetmala and Ramachandra, T. V. (2010): Small-scale decentralized and sustainable municipal solid waste management potential for Bangalore anchored around total recycle and biomethanation plants. National Conference on Urban, Industrial and Hospital Waste Management 2010., Ahmadabad Management Association.

Chanakya, H.N., (2009): "Towards a sustainable waste management system for Bangalore." 1st International Conference on Solid Waste Management (IconSWM), Kolkata.

Denison, R. A., (1996). Environmental life cycle comparisons of recycling , landfilling and incineration : A review of recent studies. Annual Review of Energy and the Environment, 21 : 191 - 237.

Finnveden, G., (1999). Methodological aspects of life cycle assessment of integrated solid waste management systems .Resources, Conservation and Recycling, 26, 173- 187.

IPCC, (1996). Guidelines for National Greenhouse Gas Inventories: Reference Manual. Revised.

ISO, (1997). Environmental management-life cycle assessment-principles and framework. Geneva, Switzerland: International Organisation for Standardisation.

Kasai, J., (1999). Life cycle assessment, evaluation method for sustainable development. J SAE Review, 20,387 - 393.

Kebin, H. E., Zhiliang. Yao, and Yingzhi. Zhang. (2010)."Characteristics of vehicle emissions in China based on portable emission measurement system." 19th Annual International Emission Inventory Conference "Emissions Inventories- Informing Emerging Issues", San Antonio, Texas.

Lakshmikantha, H. 2006. Report on waste dump sites around Bangalore. Waste Management. 26. 640-650.

Mendes, R. M., Aramaki, T., and Hanaki, K. (2004). Comparison of the environmental impact of incineration and landfilling in Sao Paulo City as determined by LCA, Resource. Conservation and Recycling, 41:47e63.

Moberg, A., Finnveden, G., and Johansson, J., Lind, P. (2005). Life cycle assessment of energy from solid waste e part 2: landfilling compared to other treatment methods. Journal of Cleaner Production, 13(3):231e40.

Pappu, A., Saxena, M., & Asolekar, S. R. (2007). Solid wastes generation in India and their recycling potential in building materials. Building and Environment, 42(6), 2311-2320.

Shekdar, A. V. (1999). Municipal solid waste management, the Indian perspective. Journal of Indian Association for Environmental Management, 26(2), 100-108.

Warith, M. (2002). Bioreactor landfills: experimental and field results. Waste management, 22(1), 7-17.

© ASCE 2014

Towards Engineering for Sustainability

Douglas Nuttall, P.Eng.

Parish Geomorphic Limited, 2500 Meadowpine Blvd., Suite 200, Mississauga, Ontario, Canada L5N 6C4; PH (905) 877-9531; FAX (905) 877-4143; email: dnuttall@xplornet.com

ABSTRACT

Traditional engineering is a process of maximizing utility while minimizing cost to the client. Engineering for Sustainability must vastly expand these concepts to become a process of 'maximizing social benefit while minimizing negative ecological impact'. This paper explores the descriptions surrounding Sustainable Development, and completes them sufficiently to include units of measure for Sustainable Technological Development. The method to measure how Sustainable any Technological Development proposal would be is derived from these definitions, and from that method, the most Sustainable alternative can be determined.

This paper introduces a relationship between the time it takes for members of a community to meet their needs and the resources consumed by the community. Canadian data is presented to provide an example of this curve. Each community, regardless of scale, will have a unique relationship due to their own assets and aspirations.

This approach focuses on the efficiency by which people use their time to meet their needs. It does not address the effectiveness of how people use their time to meet their needs.

The proposed method uses this relationship to convert excessive resource consumption into a time cost to the community. A Life Cycle Analysis is undertaken for each alternative design, using human time as the unit of measure. Any alternative that produces a positive net time benefit to the community is Sustainable. The alternative that produces the maximum net time benefit to the community is the most Sustainable.

INTRODUCTION

This paper seeks an objective test that will determine what alternative design provides the most sustainable solution to a problem, and how sustainable that alternative is. In the end, if one is bringing sustainability into the Engineering profession, one must be able to say as an expert witness: 'This is the most sustainable design alternative, and it is sustainable'. To do that, we need the units of measure of Sustainable Technological Development that we can optimize with. To find these units, we must explore the definitions and complete the descriptions surrounding sustainability that have been provided by others.

© ASCE 2014

This paper will introduce a technique for measuring the sustainability of any technological development project. It considers the impact of resource consumption in excess of what is sustainably available to the community, and how much the quality of life of the community has the potential of being changed as a result of the project. It is sensitive to, but not dependant on, the scale, culture, technology of the community, and is not bound by a defined future.

A relationship between the time it takes for members of any community to meet their needs, and the resources consumed by the community, is described using Canadian data. The relationship is unique for every community and is sensitive to the definition of 'needs' and cultural expectations. By including the concepts relating to Ecological Footprint (Wackernagel & Rees, 1996), this function can also be sensitive to resource availability. This relationship can be used to convert excess resource consumption into units of time, and thus use human time as the unit of measure of Sustainable Technological Development.

OBJECTIVES

So that the engineer can speak as an expert witness, there must be a body of definitions that are sufficiently self-consistent and robust to be able to test a product, process, or project and determine if the quality of life within the community is enhanced, in the long term. In addition, any approach to Engineering for Sustainability must be:

- **objective**, using units of measure instead of indicators.
- **repeatable**, so that anyone using the same data will produce the same results.
- **sensitive** to, but independent of: culture, climate, labour and resource availability, technology, scale of community, or an undefined future.
- **universal**, able to be applied to any discipline of engineering.
- **complete**, able to address the potential quality of life within a community, and how that potential is actualized.

FIRST PRINCIPALS

Engineers are able to derive approaches to solving problems from first principals. Unfortunately, many of the first principals of Sustainability are founded outside of an engineer's traditional approach to problem solving. They have come from professionals involved in economics, social justice, human development, and so on. Because of their varied background, the definitions are often not self-consistent, and can be perceived as conflicting, which has led some to believe that Sustainability is not a goal that can be obtained.

The following list would be the 'First Principals of Sustainability Engineering', but will require further refinement before they can be expected to provide a complete description of the required fundamentals.

- Wealth of Nations (Smith, 1776): People use their time to meet their wants and needs.
- Planning for a Sustainable Future (Projet de société, 1995) : Sustainability is about intergenerational and inter-regional equity.

© ASCE 2014

- Our Common Future (World Commission on Environment and Development, 1987): Sustainable Development is development that meets the needs of today without compromising the ability for people to meet their needs in the future.
- Measuring Sustainable Development (Joint UNECE/OECD Eurostat Working Group on Statistics for Sustainable Development, 2008): Development is the process of increasing the quality of life of a community between two points in time.
- (my understanding) Engineers maximize utility while minimizing cost to the client.
- UNDP (United Nations Development Program, 2012): Human development increases the freedoms, choices, and opportunities of people.
- Daly's Rules (Daly, 1990):
  1. We must use renewable resources slower than they renew
  2. We must use non-renewable resources slower than they can be replaced with renewable alternatives
  3. We must produce wastes slower than the environment can absorb them or render them harmless
- Human Scale Development (Max-Neef, et al., 1991): Needs are universal and invariant, and the wealth of the community comes from having needs met.

EVOLVED PRINCIPALS

- People use their time to meet their (community, family, or self) needs and wants directly, or use their time to convert resources into the means to meet their wants and needs.
- Engineers build infrastructure. Infrastructure is an investment of time and resources with an expectation of a return on that investment in the form of time and/or resources into the future.
- Sustainability Engineering is the process of maximizing the quality of life within a community while minimizing the negative ecological impacts.
- Development is the union of (at least) Human Development and Technological Development
- Technological Development is the creation or enhancement of systems of infrastructure with the expectation of an improvement in the Potential Quality of Life of a community.
- Human development actualizes the potential quality of life by removing the obstructions within the self, family, or community that prevent people from meeting their needs effectively.
- Potential Quality of Life is the time available within a community for activities other than those required to meet needs.
- Needs are aspects of Human Nature. Needs can be viewed as physical, mental, emotional, spiritual, and social. Examples would include rest, nutrition, hydration, homeostasis, fitness, understanding, love, security, governance, and so on. Needs are met by activities that prevent the degradation of the individual, family or community. The tools and infrastructure associated with needs (or wants) would be the means to meet the needs, rather than needs themselves.

© ASCE 2014

- Wants are everything that are not Needs, and they may or may not be met as part of the process of meeting needs. They are unlimited by imagination, but finite in execution, in that there is only 24 hours per day per person for all activities that meet needs and wants.
- On any scale smaller than 'planetary', Daly's Rules must be expanded to include 'a community must be able to meet its needs with the resources it manages sustainably, and the labour it has available'.

POSIT – TIME AND RESOURCE CURVE

Within any community, there is a relationship between the Resources used and the Time used to meet needs. It is in the general form of T[Time Used to Meet Needs]=a*R[Resources Used]^b+c. b is always negative, and c is the minimum time required to meet needs if resource availability were unlimited. If T=24 h/day/ca, then the community is at subsistence, and with any reduction of resource availability, it will take the community more than 24 hours per day per person to meet their needs, and they will be in a state of deprivation. When the resources used are equal to the resources available to the community, then the community is at capacity. If the community uses more resources than would be perpetually available to the community, then at some point of time the resources will cease to be available. That absence will necessarily increase the time it takes the community to meet their needs by at least the product of the slope of the resource/time curve at capacity, and the amount of resources 'lost'.

This creates a future time cost that is associated with any and all excess resource consumption. Due to synergistic effects, this approach will produce the minimum future time cost that could actually occur, and should not be considered 'conservative'.

The curve can be used to quantify the trade-offs in any Sustainability Engineering application by comparing the dT/dR for each alternative design, and finding which alternatives are a) the most Sustainable and b) if the alternative is Sustainable. The graph below shows Canadian data from 2005, derived from Size Matters (Mackenzie, 2006) and the GSS Cycle 19 (Statistics Canada, 2006). For Canada in 2005, $T = 1.899 * 10^5 * R^{-4.64} + 854.2$ min/d/ca. The coefficient of determination (R^2) of this data is better than 98%. The activities treated as 'needs' are explained in Appendix A, and the expanded data tables are in Appendix B.

Decile of household income	1	2	3	4	5	6	7	8	9,10
Time Use (min/d/ca.)	960	914	893	882	877	876	874	861	857
Ecol. Footprint (GHa/ca.)	5.03	5.66	6.34	6.48	6.93	7.36	7.67	8.12	10.6

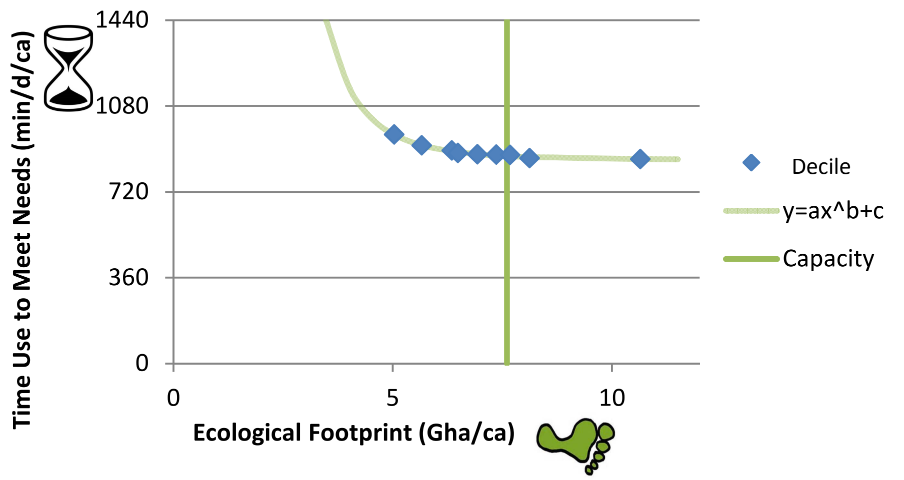
Table 1 : Resource and Time Use in Canada, 2005

This table uses Ecological Footprint (Wackernagel & Rees, 1996) to measure resources used – other approaches could be used instead. For example, the Planetary Boundaries concept (Rockström, et al., 2009) could be used equally well, and would have different strengths and weaknesses. Net Primary Production (Haberl, et al.,

© ASCE 2014

2007) could also be used. In the end, the unit of measure for Sustainable Technological Development would still be human time, but the math used to calculate the negative ecological impact would be slightly different.

Figure 1: Resource and Time Use in Canada, 2005



METHOD

- **Community** establishes their boundary of needs, and **Engineer** explains impacts of those choices.
- **Community** establishes their resource demand and supply. Where demand outstrips supply, the **Community** must establish a co-management relationship with other communities to ensure adequate resources are perpetually available.
- **Client** establishes problem.
- **Engineer** establishes a physical boundary of the community that is affected by the problem.
- **Engineer** uses a database of resource supply and demand within that boundary (including any co-management relationships).
- **Engineer** uses that database to find the capacity and the time/resource curve within the community boundary.
- **Engineer** determines the life cycle time and resources used and saved by each alternative design.
- **Engineer** applies a time cost for each alternative based on over-consumed resources, and the slope of the time/resource curve at capacity.
- **Engineer** applies a time penalty for using Non-renewable resources that would be exhausted within the community during the life cycle of the project.
- **Engineer** finds the alternative with the greatest time and resource consumption reductions = Most sustainable.

  Net time saved > 0 = Sustainable

  Maximum time saved/cost = Highest Sustainable Value

© ASCE 2014

CONCLUSION

This paper aims to provide complete definitions to allow practitioners to have a common language that is consistent with an Engineering approach. It demonstrates a method that can be used to identify the most Sustainable alternative design for any Technological Development project. The method is sensitive to, but independent of: community scale; culture; technology; resource and labour availability; and an undefined future. These are minimum requirements for any such effort, so that the engineer can say conclusively that something is or is not Sustainable, without having to qualify that statement.

The method described uses a test that is based on an evaluation of needs within a community. That evaluation can be provided by others (political means, Human Development expertise, etc.) within the community and then used wholly objectively by the engineer. The method is completely repeatable, and sufficiently sensitive to reflect nuances in design and community scale, technology, and culture. It will determine if each alternative is Sustainable, and rank the alternatives according to how Sustainable each is, and the Sustainable value of each. By using time as the unit of measure, the conditions for Sustainability per the expanded Daly rules can be met, and it can be used for any field of engineering, anywhere in the world.

Engineers must be able to apply the principals of Sustainable Development in all aspects of their work. This requirement has been difficult if not impossible to apply consistently. By building onto what has been started by others, this paper opens the door to provide holistic collaboration with the other professional disciplines, so that Sustainability can be authenticated, and implemented in a coherent, consistent, and practical manner.

ACKNOWLEDGEMENTS

The author would like to thank Andrea Brett for her tireless efforts at not accepting good enough as being good enough. Dr. Linda Harvey and Roddy Bolivar, P.Eng. have provided ongoing critical conversations that have focused many of the points made. Many others have provided thoughtful feedback, including but not limited to Dr. Fiona Crofton, Dr. Joshua Pierce, P.Eng., Bina Chadaburty, P.Eng., Steve Graham, P.Eng, and Dr. Gunter Musbacher.

REFERENCES

Daly, H., 1990. *Toward some operational principles of sustainable development*. Ecological Economics, 2(1), pp. 1-6.

Haberl, H. et al., 2007. *Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems*. Proceedings of the National Academy of Science, Issue 104, pp. 12942-12947.

Joint UNECE/OECD Eurostat Working Group on Statistics for Sustainable Development, 2008. *Measuring Sustainable Development*, New York and Geneva: United Nations.

© ASCE 2014

MacKenzie, H., Messenger, H. & Smith, R., 2008. *Size Matters, Canada's Ecological Footprint, by Income*: Canadian Centre for Policy Alternatives.

Max-Neef, M. A., Elizalde, A. & Hopenhayn, M., 1991. *Human Scale Development*. *New York:* The Apex Press.

Projet de société, 1995. *Canadian Choices for Transitions to Sustainability*, Ottawa: s.n.

Rockström, J. et al., 2009. P*lanetary boundaries:exploring the safe operating space for humanity*. Ecology and Society, 14(2).

Smith, A., 1776. *An Inquiry into the Nature and Causes of the Wealth of Nations*. London: W. Strahan and T. Cadell.

Statistics Canada, 2006. *Cycle 19 Global Social Survey*, 12M0019XCB, Ottawa: Statistics Canada.

United Nations Development Program, 2012. *About Human Development*. [Online] Available at: http://hdr.undp.org/en/humandev/ [Accessed 23 02 2012].

Wackernagel, M. & Rees, W., 1996. *Our Ecological Footprint*. Gabriola Island, British Columbia, Canada: New Society Publishers.

World Commission on Environment and Development, 1987. *Our Common Future*. Oxford: Oxford University Press.

© ASCE 2014

APPENDIX A. GSS and NAICS Codes Used

The deciles of household income were established using 2005 data from Statistics Canada, and the GSS data within each range was assumed to be evenly distributed within that range. The fraction of the ranges that lined up with each decile was determined, and the average time use within each range was distributed to the appropriate decile.

To find the average time within each decile, the entire time use database has been split out into: rest, food, clothing, shelter, water/hygiene/sanitation, fitness, education, childcare, health care, and community development. Some of these have some overlap, so fitness would include preventative ‘medicine’, while health care include reactive ‘medicine’, regardless of whether that is physical, mental, emotional or spiritual health. All other codes would be considered ‘wants’ and excluded from the analysis.

First order activities to acquire, transport, utilize, and ultimately dispose of any of the materials required for a ‘need’ will be considered ‘needs’, but not past that. So, under Food, there would be food growers, distributers, and retailers, and waste haulers, but not the road builders to bring crops to market, truck builders for hauling crops, diesel oil production, mechanics, supermarket builders, etc. In some future, a second or even third order analysis could be completed to get closer to reality, but for now, this should provide a reasonably close approximation.

Without accurate consumption data, it is not clear whose needs are being met by employment. Household activities meet household needs, but employment activities do not necessarily meet the needs of the employee. A doctor meets needs by providing health care, but does not provide their own. It is reasonable to expect that it takes poor people more time to have their needs met (for instance, health care dollars spent with respect to income is skewed toward the lower incomes). It is not obvious from the data analysed what the distribution of the time consumption is with respect to household income. Said another way, we know the income of who is making the resource available, but not of who is consuming the resource, considering human time as that resource. It would not be expected that the amount of time spent by wealthy households to purchase needs would be significantly greater than the amount of time spent by poor households, so the slope of the time/resource curve may be approximately the same while not including this data. This must yet be confirmed in a refined analysis.

As a result, the NAICS codes were not used in this analysis. They are listed to begin the discussion of the codes that would be used to produce the refined analysis.

GSS CODES

<u>Rest</u> would include GSS codes of 450, 460, 470.

© ASCE 2014

Food would include GSS codes of 50, 101, 102, 110, 184, 301, 303, 430, 431, 440, 540, 642, 661.

Clothing would include GSS codes of 140, 151, 152, 302.

Shelter would include GSS codes of 161, 162, 164, 182, 183.

Fitness would include GSS codes of 411, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 821, 822, 880.

Education would include GSS codes of 500, 511, 512, 520, 530, 550, 590.

Childcare would include GSS codes of 200, 211, 212, 213, 220, 230, 240, 260, 281, and 673.

Water/Hygiene/Sanitation would include GSS codes of 120, 271, 400, 480.

Health Care would include GSS codes 250, 272, 282, 340, 410, 675.

Community Development would include GSS codes of 600, 610, 620, 630, 640, 651, 652, 660, 671, 672, 678, 680, and 800.

NAICS CODES

Food would include NAICS codes of 1111, 1112, 1113, 1119, 1121, 1122, 1123, 1124, 1125, 1141, 1151, 1152, 3112, 3113, 3114, 3115, 3116, 3117, 3118, 3119, 3253, 4111, 4131, 4171, 4183, 4451, 4452, 4931.

Clothing would include NAICS codes of 3131, 3132, 3133, 3151, 3152, 3159, 3161, 3162, 3169, 4141, 4481, 4482, 8123.

Shelter would be NAICS codes of 1131, 1132, 1133, 1153, 2361, 2372, 2381, 2382, 2383, 2389, 3211, 3212, 3219, 3272, 4161, 4163, 4172, 4441, 5617, 6233, 7213.

Education would be NAICS codes of 6111, 6112, 6113, 6114, 6115, 6116, 6117.

Childcare would be NAICS code 6244

Water/Hygiene/Sanitation would be NAICS codes of 2213, 2371, 3256, 4145, 5621, 5622, 5629, 8122.

Health Care would be NAICS codes 3254, 4461, 6211, 6212, 6213, 6214, 6215, 6216, 6219, 6221, 6222, 6223, 6231, 6232, 6233, 6239.

Security would be NAICS codes 9111, 9112, 9121, and 9131.

Community Development would NAICS codes 8131, 8132, 8133, 8134.

© ASCE 2014

Appendix B –Data

Table B1 – Time Use Data Summary

	Household income categories from Time Use Data											
	1	2	3	4	5	6	7	8	9	10	11	12
count	138	87	339	760	769	1517	1810	1551	1598	2126	1450	2307
Average time (min/d/ca)	985	1012	971	948	928	901	885	877	877	874	860	857
Stadev	255	228	250	233	229	237	241	243	243	241	248	246
Max	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440
80 %ile	1209	1245	1200	1156	1134	1110	1110	1098	1100	1110	1101	1095
Median	990	995	975	945	920	890	860	850	840	838.5	820	810
20 %ile	745	797	740	740	720	690	670	660	660	660	650	650
Min	240	546	135	210	325	20	100	40	90	60	210	110
Averages, per category (min/d/ca)												
Rest	566	578	577	563	550	537	521	524	513	508	504	500
Food	135	109	128	135	143	133	131	126	127	125	123	120
Clothing	28	20	22	27	25	24	26	24	23	27	23	21
Shelter	2	1	9	8	10	14	14	13	18	18	16	14
Fitness	22	35	29	25	24	24	28	28	28	32	31	30
Education	99	134	44	28	30	24	18	15	19	15	17	18
Childcare	11	21	16	19	17	16	19	24	25	27	28	30
H2O/hyg./sani.	72	75	74	82	78	69	73	69	66	64	63	62
health care	2	1	14	9	6	6	4	5	4	5	4	4
mobility for household	18	22	26	28	25	31	32	31	34	34	35	38
Community	27	11	25	20	16	20	16	15	17	16	14	14
mobility for community	4	5	5	4	6	4	4	4	4	4	4	4
Employment	54	59	72	78	113	157	197	221	228	241	272	278
employment to meet needs	17	24	27	32	47	74	91	104	111	117	128	127
mobility for employment	6	7	8	8	10	15	18	21	21	23	30	31

Source: Statistics Canada, Cycle 19 Global Social Survey, 12M0019XCB, 2006. This analysis is based on the Statistics Canada General Social Survey, Cycle 19: Time Use, 2005. All computations, use and interpretation of these data are entirely that of Douglas Nuttall, P.Eng.

© ASCE 2014

Table B2 – Ecological Footprint Data Summary

Ecological Footprint (Gha/household) using EF 1.0	Deciles of household income										
	1	2	3	4	5	6	7	8	9	10	average
Food	2.06	2.15	2.14	2.14	2.14	2.16	2.15	2.16	2.13	2.24	2.13
Housing	1.51	1.82	1.79	1.73	1.88	1.98	2.06	2.19	2.31	3.4	2.16
Mobility	0.36	0.62	0.88	1.04	1.2	1.43	1.55	1.74	2.17	3.23	1.43
Goods	0.56	0.74	0.82	0.85	0.93	1	1.09	1.16	1.33	2.11	0.97
Services	0.55	0.68	0.71	0.74	0.79	0.82	0.83	0.89	0.95	1.48	0.74
Energy Land	2.82	3.23	3.74	3.89	4.18	4.5	4.68	5.01	5.66	7.84	4.59
Cropland	0.88	0.95	1.03	1.03	1.06	1.09	1.12	1.13	1.14	1.56	1.07
Pasture	0.3	0.32	0.34	0.34	0.35	0.36	0.37	0.37	0.38	0.52	0.36
Forest	0.89	1	1.05	1.06	1.17	1.23	1.31	1.41	1.48	2.21	1.29
Built area	0.04	0.04	0.05	0.05	0.05	0.06	0.06	0.07	0.07	0.11	0.06
Fishing Grounds	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.17	0.12
Total	5.03	5.66	6.34	6.48	6.93	7.36	7.67	8.12	8.87	12.42	7.49

from Size Matters, 2008, Canadian Centre for Policy Alternatives, By Hugh Mackenzie, Hans Messinger, Rick Smith

© ASCE 2014

Table B3 – Combined Data

Deciles of household income

Time Use (minutes/day) of respondent, GSS Cycle 19

	1	2	3	4	5	6	7	8	9, 10
EF	5.03	5.66	6.34	6.48	6.93	7.36	7.67	8.12	10.645
count	1400	1402	1503	1613	1665	1601	1488	1377	2404
rest	567	544	530	522	520	511	508	504	500
food	132	138	132	129	126	126	125	123	120
clothing	25	25	25	25	23	24	27	23	22
shelter	8	12	14	14	15	18	18	16	14
fitness	26	24	26	28	28	30	32	31	30
education	46	27	21	17	16	17	15	17	18
childcare	18	17	18	21	24	26	27	28	30
H2O/hyg./sani.	79	73	71	72	68	65	64	63	62
health care	9	6	5	4	5	4	5	4	4
mobility for household	26	28	31	31	32	34	34	35	38
Community	21	18	18	16	16	16	16	14	14
mobility for community	4	5	4	4	4	4	4	4	4
sum	960.0	914.3	893.3	882.2	876.9	875.7	874.0	860.7	857.0
employment	34	135	175	204	224	233	241	271	277
employment to meet needs	13	61	82	95	107	113	117	128	127
mobility for employment	4	13	17	19	21	22	23	30	31

Source: Statistics Canada, Cycle 19 Global Social Survey, 12M0019XCB, 2006. This analysis is based on the Statistics Canada General Social Survey, Cycle 19: Time Use, 2005, All computations, use and interpretation of these data are entirely that of Douglas Nuttall, P.Eng.

© ASCE 2014

Sustainable Rest Areas Design and Operations

Arthur H. Hirsch, ENV-SP,SV, LEED AP

TerraLogic Sustainable Solutions, 5766 Flagstaff Road, Boulder, Colorado 80302; PH (303) 786-9111; email: AHirsch@TerraLogicss.com

ABSTRACT

The research project focused on the evaluation of Colorado Department of Transportation's rest areas related to sustainable design and operations. A sustainability assessment was performed on six selected rest areas focusing on sustainable design and operations. Sustainable rest area assessment and scoring criteria developed by the TerraLogic and Colorado State University-Pueblo Team used a checklist approach that involved the following criteria: existing site conditions, materials recycling and reuse, existing environment, air quality, water quality/usage, energy and public/motorist/trucking outreach and services. Rest area carbon footprints were calculated and carbon reduction strategies developed primarily for long term idling trucks. Cost effective sustainable recommendations were provided that focused on efficient use of water resources, solid waste management, and energy efficiency. Recommendations included native landscaping, reductions in lawn irrigation, material recycling, water saving faucets, lighting motion detectors and LED lighting. Research identified the potential of using public private partnerships to support funding innovative rest area operations.

INTRODUCTION

The functional and amenity expectations of rest areas by the public have substantially grown over the past decade. Meeting these expectations and increased safety concerns has resulted in the addition of features such as high intensity lighting, air conditioning, paving, and grassy areas. Maintaining and operating these features comes at increased environmental and economic costs.

The purpose of the Project was to assess sustainable rest area design and operations from a representative sample of rest areas in Colorado and evaluate the potential for economic savings and natural resource conservation. The team of TerraLogic Sustainable Solutions and Colorado State University at Pueblo (CSU-Pueblo) were selected by the Colorado Department of Transportation (CDOT) to perform the rest area sustainability analysis at six rest areas that were selected as representative of CDOT rest area design and operations.

© ASCE 2014

Onsite evaluations were performed by the Team in the months of July and August, 2010. The Project Rest Areas were evaluated using a sustainability evaluation checklist that focused upon the following areas:

- Site Conditions - current year round operating conditions and activities of the Project rest areas
- Materials, Recycling and Reuse - solid waste management practices at the Project rest areas
- Environment - existing environmental conditions and harmony with wildlife habitat
- Air Quality - identifies activities that could affect air quality at the Project rest areas such as chemicals used/stored, overnight truck parking, etc.
- Water Quality/Usage - identifies the measures taken to protect water quality and identifies rest area water usage such as for irrigation and restroom services
- Energy - energy usage, management practices and costs at the Project rest areas
- Public/Motorist/Trucking Outreach and Services- identifies the community involvement and impacts by the operation and use of the rest area

Unique to rest area research studies was the development of rest area carbon footprints. The rest area carbon footprint provided a unique way of reviewing and assessing overall energy consumption and resulting emissions. The method used by the Team was consistent with the Greenhouse Gas Protocol (GHGP) established by the World Resource Institute (WRI, 2004). This project will provide CDOT environmental personnel, who are responsible for greenhouse gas management, information on the amount of direct and indirect loading that occurs for specific rest areas and an overall cumulative estimate on greenhouse gas annual loading.

This Project provided CDOT with rest area-specific observations and recommendations for sustainable rest area designs, and operation and maintenance. These recommendations were provided to help improve the overall environment, conserve finite resources, enhance the visitor experience and reduce rest area operational costs.

Safety Rest Area History and Overview. Safety rest areas (rest areas) were constructed as part of the Interstate Highway System, and were modeled after roadside parks. Rest areas were initially intended to provide minimal comfort amenities for the traveling public; generally consisting of toilet facilities, drinking water, picnic grounds and information dispersal. In 1958, a Policy on Safety Rest Areas was developed by the American Association of State Highway Officials to standardize the design and construction of rest areas. As a result of uniform design and function requirements, design aesthetics moved toward the tradition of roadside architecture. This roadside architecture came to dominate American highways and rest area sites emerged as unique and colorful expressions of regional flavor and modern architectural design (FHWA, 2010).

© ASCE 2014

The safety function of rest areas over the past several years has remained the same since the creation of the Interstate Highway System; however, there have been dramatic changes in design and operation of rest areas to accommodate the expectations of modern travelers. Where rest areas used to provide the connection of people to a local region, commercial truck stops now provide the major service to travelers for food, petroleum fuels and area connection.

CDOT currently owns and operates 32 rest areas throughout Colorado. These facilities are visited by thousands of travelers every year, offering temporary parking for cars, recreational vehicles (RVs), and semi-trailer trucks. For many first-time visitors to Colorado, highways and their rest areas create a strong first impression of the State. CDOT is concerned about the increasing costs of maintaining rest area services and operations at high standards, in light of tight maintenance budgets.

Meeting increasing service demands has resulted in increased maintenance and operational costs (Rest Area History, 2010). Rest area design and function has been upgraded and modified within the past 10 years to provide the motoring public with new amenities such as air conditioning, flush toilets/urinals, security lighting, vending machines, pet walks, lighted truck parking, sewage disposal and visitor information centers. It has also resulted in increased impervious surfaces, more storm water runoff, higher potential for pollutant discharges into local water resources, more non-native grassed areas and higher irrigation and lighting intensity.

PROJECT GOALS AND OBJECTIVES

As part of the Project, CDOT directed the development of a Sustainable Rest Areas Task to address the economic, environmental and social (traveling public) impacts of rest area operations. Onsite evaluations of six selected rest areas were performed by TerraLogic and CSU-Pueblo Team (Team) using sustainability based assessment of rest area design and operation and maintenance.

The purpose of this task was to conduct energy and conservation audits of CDOT rest areas with regard to current resource consumption, energy costs, emissions and types of waste treatment. The findings from the assessments were used by CDOT to identify recommendations for cost-effective methods to retrofit or improvement options for the facilities that may reduce CDOT operating costs. The goals for this rest area sustainability evaluation study were to provide recommendations that CDOT can consider to:

- Reduce life cycle cost for energy, materials and CDOT manpower
- Conceptualize sustainable and renewable actions and features for rest areas
- Improve the visitor experience in Colorado
- Reduce long-term rest area operation and maintenance costs and avoid a large manpower-resource commitment by CDOT maintenance
- Develop sustainable retrofit or improvement recommendations
- Evaluate the resulting environmental footprint achieved by reducing emissions, conserving natural resources and protecting the local environmental conditions

© ASCE 2014

- Evaluate the carbon footprint of the Project rest areas and identify reduction strategies for rest areas to potentially reach carbon neutrality
- Estimate the carbon footprint for all CDOT rest areas combined

PROJECT METHODOLOGY

The following methodology was developed and implemented by the Team in coordination with CDOT in order to achieve the goals and objectives and critical elements of the Project:

- Selection of Project rest areas
- Perform a literature search on sustainable rest area studies
- Develop and complete Sustainable Rest Area Field Evaluation Checklists
- Coordinate with CDOT representatives
- Conduct onsite evaluations of Project rest areas
- Develop and complete the Sustainable Rest Area Evaluation Database
- Develop and apply the Sustainable Rest Area Scoring Criteria
- Calculate Project rest area carbon footprints

Rest Area Selection. CDOT currently owns and operates 32 rest areas throughout Colorado. These facilities are visited by thousands of travelers per year, offering temporary parking for cars, recreational vehicles (RVs), and semi-trailer trucks. There are three types (Tiers) of CDOT rest areas that were identified by the Team based upon rest area services and function:

- Tier I Rest Areas contain or are adjacent to visitor centers. These rest areas are larger in size, receive the most motorist visitation and provide numerous amenities such as air conditioning,
- Tier II Rest Areas are located in recreational areas and are more destination-oriented than other rest area types. These types of rest areas provide services to motorists, tourists, bicyclists and hikers.
- Tier III Rest Areas provide basic services to the traveling public and trucking industry. They are limited in the type of public services and center mostly upon restroom facilities and picnic tables.

Six rest areas were selected as representative of Tier I, II and III rest areas. Two rest areas for each of the Tiers were selected to comprise a group of rest areas with the following criteria.

- Rest area classified as either Tier I, II or III rest areas
- At least one rest area resides within every CDOT Region (except the CDOT Urban Region 6 since no rest areas exist)
- At least one rest area resides within each type of eco-region (desert, mountains, canyon, and plains)

Using these selection criteria, the following rest areas (Project rest areas) were selected for the study:

- Sterling Rest Area Tier I-Visitor Center; Region 4; plains eco-region

© ASCE 2014

- Poudre Rest Area Tier I- Adjacent to Existing Visitor Center (newest); Region 4; plains eco-region
- Vail Pass Rest Area-Tier II-Recreational Rest Area/Region 1; mountain eco-region
- Hanging Lake Rest Area- Tier II- Recreational Rest Area/Region 3; canyon eco-region
- El Moro Rest Area-Tier III- Basic Services/Region 2; high plains eco-region
- Sleeping Ute Mountain Rest Area-Tier III- Basic Services/Region 5; desert eco-region

Sustainable Rest Area Field Evaluation Checklist Development. The Sustainable Rest Area Field Evaluation Checklist was developed to assist the Team in assessing the Project rest areas. The development of the sustainability criteria mainly referenced the Leadership in Energy and Environmental Design (LEED) Checklist categories and criteria (USGBC, 2007). A list of evaluation parameters was developed within the following broad categories:

- Site Conditions – This category establishes the baseline conditions by detailing the current year round operating conditions and activities of the Project rest areas
- Materials, Recycling and Reuse - This category is related to the conservation of natural resources by using material reuse and recycling. Material recycling and reuse reduces that amount of solid waste that is transported and ultimately landfilled.
- Environment – This category evaluates how well the rest area is in harmony with the overall local environment such as wildlife habitat and mobility.
- Air Quality – This category identifies activities that could affect air quality at the Project rest areas such as toxic chemicals used/stored, overnight truck parking, etc. Rest area actions that impact air quality are the emission of greenhouse gases and the exposure of chemicals to the rest area worker and the rest area visitor.
- Water Quality/Usage – This category identifies the measures taken to protect local water quality and identifies rest area water usage such as for irrigation and restroom services. Water is a very finite resource within Colorado and water conservation is very important and cost effective.
- Energy – This category relates to energy usage, management practices and costs at the Project rest areas. Rest area energy is expensive and is generated by finite fossil fuel resources that add to the greenhouse gas loading in the State of Colorado.
- Public/Motorist/Trucking Outreach and Services – This category represents how well the local community is being involved with the operation of the rest area (regional information, free coffee) and the level of services provided to the traveling public (maps, weather forecasts).

The 61 sustainable scoring criteria elements were grouped into the following categories with the maximum number of points per category. These categories are similar to those contained in the Sustainable Rest Area Field Evaluation Checklist:

© ASCE 2014

- Materials and Reuse/Recycling (13 points)
- Environment/Site Conditions (25 points)
- Air Quality (13 points)
- Water Quality/Usage (21 points)
- Energy (30 points)
- Public/Motorist/Trucking Outreach (11 points)
- Innovation Score (4 points)
- Maximum Score (117 points)

Calculation of Project Rest Areas' Carbon Footprints. The calculation of the Project rest areas' carbon footprints is a unique evaluation approach to determine rest area impact upon the environment by estimating greenhouse gas emissions. The rest area carbon footprint provides a way of reviewing and assessing overall energy consumption and resulting emissions. The carbon footprint provides the baseline to which carbon reduction options can be identified and measured against in an attempt to achieve carbon neutrality for each rest area.

The method used by the Team was consistent with the Greenhouse Gas Protocol (GHGP) established by the World Resource Institute (WRI, 2004). The GHGP approach is a well established and accepted method for carbon footprint calculations. The carbon footprint calculation followed the method used by EPA; multiplying the volume or amount of fuel combusted by an emission factor (EPA, 2005).

The GHGP approach identifies three Scope Emission types to identify and estimate direct and indirect emission sources. These Scope Emissions (Scope 1, Scope 2 and Scope 3) are used to provide consistency in accounting for and mitigating greenhouse gas emissions (IPCC, 2007). The following summarizes the GHGP scopes as they relate to the Project rest areas:

Scope 1 - Direct GHG Emissions: these type of emissions come from combustion sources that are owned by the entity (CDOT) that are directly related to the operations of the rest area such as propane and natural gas for heating, and gasoline/diesel fuel for the transportation of materials, equipment, mowing and personnel transportation to and from work. For a rest area that uses electricity for heating and gasoline for operation and maintenance the equation used for Scope 1 emissions were:

Emission factor-CO2 = 8.8 Kg/gallon
Emission factor –N2O = 0.000199 Kg/gallon
Emission factor – CH4 = 0.00182 Kg/gallon
GWP- CO_2 = 1
GWP- N_2O = 310
GWP- CH_4 = 21

© ASCE 2014

$$(\text{gallons gasoline}) \times 8.8 \left(\frac{\text{KgCO}_2}{\text{Gal}}\right) \times \frac{\text{1MetricTon}}{\text{1000Kg}} + (\text{gallons gasoline}) \times (0.000199) \left(\frac{\text{KgN}_2\,\text{O}}{\text{Gal}}\right) \times \frac{\text{1MetricTon}}{\text{1000Kg}} \times 310 \text{ GWP} + (\text{gallons gasoline}) \times (0.00182) \left(\frac{\text{KgCH}_4}{\text{Gal}}\right) \times \frac{\text{1MetricTon}}{\text{1000Kg}} \times 21 \text{ GWP} = \frac{\text{Metric Ton}}{\text{yr}} \text{of } \text{CO}_2 \text{ e}$$

Scope 2 - Electrical Indirect GHG Emissions: accounts for GHG emissions from the generation of purchased electricity consumed by the company (CDOT). The actual emissions occur at the power facility where the electricity is generated. This type of indirect emission will be used for rest area heating/cooling and lighting and was expected to be the largest type of emission for rest areas. The equation used for Scope 2 emissions was the following:

Usage (KWh) X CO_2 emission factor (lbs CO_2/KWh) / 2204.62 1bs/metric ton + Usage (KWh) X CH_4 emission factor (lbs CH_4/KWh) / 2204.62 1bs/metric ton X 21 GWP + Usage (KWh) X N_2O emission factor (lbs N_2O/KWh) / 2204.62 1bs/metric ton X 310 GWP = CO_2e /Metric Ton/year

Scope 3 - Other Indirect GHG Emissions: these types of emissions are a consequence of activities of the company (CDOT) but occur from sources not owned or controlled by the company (CDOT). The main rest area source for this type of indirect emission is from truck idling. The equation used to calculate Scope 3 emissions was the following:

Diesel fuel consumption per year (gallons per year idling)
Emission factor- CO_2 =10 Kg/gallon
Emission factor- CH_4 = 0.000199 Kg/gallon
Emission factor- N_2O = 0.18 kg/gallon
GWP- CO_2 = 1
GWP- N_2O = 310
GWP- CH_4 = 21

$$\left((gal/year) \times 10 \left(\frac{KgCO_2}{Gal}\right) \times \frac{1MetricTon}{1000Kg} + (Gal/year) \times (0.18) \left(\frac{KgN_2\,O}{Gal}\right) \times \frac{1MetricTon}{1000Kg} \times 310\ GWP\right) = metric\ \frac{ton}{year}\ of \text{CO2}\ e$$

The number of trucks and their idling hours are estimates provided by each CDOT rest areas maintenance representatives. No direct quantitative measurement was performed during the study.

Rest Area Sustainability Scoring. Rest Area Sustainability Scoring Criteria were developed as a tool to assess the level of sustainability practices currently being used

© ASCE 2014

at the Project rest areas, and provide a metric for Project rest area comparison among scoring elements and categories. The scoring matrix is composed of 6 categories comprising a total of 61 scoring elements with 117 being the maximum number of points per rest area. The following summarizes the scoring comparison (Table 1):

- Tier I rest area (visitor center type rest area) - Poudre Rest Area (33 points) higher than the Sterling Rest Area (30 points)
- Tier II rest area (recreational based rest area) - Vail Pass Rest Area (37 points) higher than Hanging Lake (31 points)
- Tier III rest area (basic rest area services) - Sleeping Ute Mountain Rest Area (35 points) higher than the El Moro Rest Area (32 points)
- Overall, the Vail Pass Rest Area obtained the most sustainability points among all the Project rest areas with a score of 37 points; innovation points were given due to recycling of sludge material from the waste water treatment facility.
- The scoring distribution was very close among the rest areas with a point spread from 30-37 and a mean of 33 points.

Categories	Maximum Points	Sterling	Poudre	Hanging Lake	Vail Pass	El Moro	Sleeping Ute Mountain
Total Materials and Reuse Score	13	6	3	1	1	5	5
Total Environment/Site Conditions	25	5	9	10	12	7	10
Total Air Quality	13	2	2	2	2	2	2
Total Water Quality/Usage	21	7	5	2	2	3	3
Total Energy	30	6	7	10	6	11	9
Total Public/Motorist/Trucking Outreach	11	4	7	5	5	4	6
Innovation Score	4	0	0	0	4	0	0
Total Rest Area Scoring	**117**	**30**	**33**	**31**	**37**	**32**	**35**

Table 1. Summary of project rest area sustainability scoring

Rest Area Carbon Footprints. Carbon footprints were calculated for all the Project rest areas which incorporate scope 1 emissions (fossil fuel combustion onsite), scope 2 emissions (indirect emissions from electrical consumption) and scope 3 emissions (uncontrolled emissions such as idling). The following summarizes the carbon footprint results for the Project rest areas (Table 2):

- The Tier I rest areas (visitor centers) carbon footprints were 3,006 metric tons metric tons CO_2e/year for the Sterling Rest Area and 2,517 metric tons

CO_2e/year for the Poudre Rest Area; truck idling emissions account for 94-95% of total carbon footprint emissions. The average carbon footprint for the Tier I rest areas was 2,762 metric tons CO_2e/year.

Emission Scope	Sterling	Poudre	Hanging Lake	Vail Pass	El Moro	Sleeping Ute Mtn.
Scope 1 Carbon Footprint (operations - metric tons CO_2e/year)	44	15	10	11	59	23
Scope 2 Carbon Footprint (electrical consumption - metric tons CO_2e/year)	108	123	133	230	2	50
Scope 3 Carbon Footprint (idling -metric tons CO_2e/year)	2854	2377	0	645	2219	0
Total Carbon Footprint (metric tons CO_2e/year)	3006	2517	143	886	2281	73
Scope 3 Emission - % of Total	95%	94%	0%	73%	97%	0%

- **Table 2. Summary of project rest area carbon footprints**

- The Tier II rest areas (recreational areas) carbon footprints were 886 metric tons CO_2e/year for the Vail Pass Rest Area and 143 metric tons CO_2e/year for the Hanging Lake Rest Area. Higher electrical usage for heating, lighting and waste treatment operations resulted in a higher overall carbon footprint for the Vail Pass Rest Area. The average carbon footprint for the Tier II rest areas was 515 metric tons CO_2e/year.
- The Tier III rest areas (basic services) carbon footprints were 2,281 metric tons CO_2e/year for the El Moro Rest Area and 73 metric tons CO_2e/year for the Sleeping Ute Mountain Rest Area; higher natural gas usage, and truck idling were the main reasons for the higher footprint value at the El Moro Rest Area. The average carbon footprint for the Tier III rest areas was 1,177 metric tons CO_2e/year.

© ASCE 2014

- There were no Scope 3 emissions associated with the Hanging Lake and Sleeping Ute Mountain since no large truck parking and idling occurs due to space limitations.
- The Sterling Rest Area had the highest carbon footprint among all the Project rest areas with a carbon emission value of 3,006 metric tons CO_2e/year; whereas the Sleeping Ute Mountain Rest Area had the lowest carbon footprint value of 73 metric tons CO_2e /year.
- The metric tons CO_2e/year per restroom square foot were the highest at the Poudre Rest Area (1 metric ton/square foot) followed by the El Moro Rest Area (0.95 metric ton/square foot).
- The metric tons of CO_2e/year per acre were the highest for the Sterling Rest Area (429 metric tons CO_2e/year metric tons/acre) followed by the El Moro Rest Area (321 metric tons CO_2e/year).
- It is possible that the Sleeping Ute Mountain Rest Area is the only Project rest area that is close to being carbon neutral. The total carbon footprint was 73 metric tons CO_2e/year and the total amount of mature trees for carbon sequestration within the 10.4 acre rest area was 820 Juniper and Pinon Pine trees (82 trees/acre). No sequestration studies were performed for Sleeping Ute Mountain Rest Area.

OBSERVATIONS AND RECOMMENDATIONS

Rest Area Operations Information. Operational information such as electricity and water consumption were difficult to obtain from CDOT. It was not possible to separate out specific rest area operations (waste treatment, parking lighting, heating, etc) for electric consumption data; therefore it was hard to track specific electrical consumption for an operation over time. Water consumption data (restroom, irrigation) was also difficult to identify. Most of the CDOT maintenance managers or rest area representatives do not regularly obtain or review resource consumption data. Maintenance managers could be reviewing consumption information to identify problem areas and areas for improved conservation. Electrical and water data can also be monitored and logged routinely by rest area personnel.

Restroom Water Conservation. Water is a valuable finite resource, especially in Colorado. Water is used by the rest areas for restroom services and lawn irrigation. Some rest areas purchase water from municipalities while some rest areas have onsite domestic water sources. Automatically timed flushing generates high volumes of water for treatment and discharge (for example, the Hanging Lake Rest Area has an estimated annual discharge of 243,855 gallons per year). Cost savings could be achieved and less water used if rest areas performed restroom conservation studies and routinely monitored water usage. Waterless urinals were estimated to be cost-effective for the Sterling, El Moro and Vail Pass rest areas. It is possible that CDOT could reduce operational costs by: 1) reduced domestic water purchasing, 2) reduced cost for municipal waste treatment, 3) reduced onsite consumption of waste treatment chemicals and 4) reduced electrical usage from pumps.

© ASCE 2014

Lawn Irrigation and Landscaping. Some rest areas have large areas of open space that are occupied by non-native and native vegetation. Large amounts of water are used by most rest areas to irrigate high demand non-native vegetation such as bluegrass. Fertilizers are applied to most of these areas to promote an aesthetic green color that requires frequent mowing, labor and lawn irrigation. There could be a transition away from high water demand, non-native vegetation and toward xeriscape landscaping using low water demand, drought tolerant plant species. It requires six times the amount of water to maintain a bluegrass lawn than a buffalo grass lawn (CSU, 2010). This transition could save CDOT financial resources by not having to purchase domestic water from municipalities, reducing electrical cost of those for irrigation pumping, limiting contractor costs who apply a fertilizer/herbicide mixture to lawns, and reducing labor and equipment costs from reduced mowing operations.

Solid Waste Management. Solid waste is generated at rest areas by site operation and maintenance activities and by the traveling public and trucking professionals. Rest area operations generate waste in the form of paper, cardboard, grass, cleaning materials and miscellaneous trash. A significant amount of solid waste from the traveling public and trucking professionals is in the form of paper waste, trash, and beverage containers made of plastic, glass and aluminum. CDOT currently has no rest area program or directive to recycle solid waste from rest areas. It was recommended that CDOT institute a rest area recycling program to collect and transfer recyclables (metal, glass, aluminum, plastic, cardboard, office paper and paperboard) to local recycling centers.

Rest Area Energy Conservation. Rest areas consume electric, propane and natural gas energy for lighting, heating, air conditioning and waste treatment operations. Energy is also consumed by CDOT vehicles and equipment (diesel and gasoline) for the movement of equipment, personnel, mowing and snowplowing. It was recommended that an energy conservation study be performed for CDOT rest areas to reduce operating costs, avoid inefficient use of energy and reduce the overall carbon footprint. Energy conservation actions could be investigated and performed at rest areas such as motion detectors to initiate nighttime lighting, turning off lights during daytime hours, energy efficient lighting systems, and use of alternative energy (solar, wind and geothermal).

Truck Idling Emissions. Truck idling emissions (Scope 3 emissions) constitute the major source of greenhouse gas emissions at the Project rest areas (over 90% at Tier I rest areas). In addition to greenhouse gases, truck idling emits fine particulates and fumes and generates noise at the rest areas. A significant amount of diesel fuel is inefficiently used by truck idling. Truck idling provides trucking professionals with cab heating, air conditioning and power for computers and appliances. Auxiliary power units can be purchased by trucking companies or by independent truckers to avoid the need for idling by plugging into provided electrical outlets (truck electrification). CDOT could develop truck idling restrictions to or significantly limit long-term idling within rest areas.

© ASCE 2014

REFERENCES

Colorado State University (CSU). (2010). Water Conservation In and Around the Home, No. 9.052, http://www.ext.colostate.edu/pubs/consumer/099952.html.
United States Environmental Protection Agency Office of Transportation and Air Quality (EPA). (2005). "Emission Facts; Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel); EPA420-F-05-001
Federal Highway Administration (FHWA). (2010). "Dwight D. Eisenhower National System of Interstate and Defense Highways", http://www.fhwa.dot.gov/programadmin/interstate.cfm (2010)
Intergovernmental Panel on Climate Change (IPCC). (2007). Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf
Jakubski, P. (2008) "Calculating and Reducing Your Carbon Footprint." <http://www.pneac.org/publicationoftheyear/Calculating-and-Reducing-Your-Carbon-Footprint.pdf
Rest Area History. (2010). Rest Area History.org; http://www.restareahistory.org/History.html
United States Green Building Council (USGBC). (2007). "Leadership in Energy and Environmental Design, New Construction".
World Resource Institute (WRI). (2004). "The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard"

© ASCE 2014

Social Sustainability Evaluation Matrix (SSEM) to Quantify Social Aspects of Sustainable Remediation

Krishna R. Reddy[1], Bala Yamini Sadasivam[2], and Jeffrey A. Adams[3]

[1]Professor, University of Illinois at Chicago, Department of Civil and Materials Engineering, 842 West Taylor Street, Chicago, IL 60607; e-mail: kreddy@uic.edu
[2]Graduate Research Assistant, University of Illinois at Chicago, Department of Civil and Materials Engineering, 842 West Taylor Street, Chicago, IL 60607; e-mail: bsadas2@uic.edu
[3]Associate, ENGEO Incorporated, 2010 Crow Canyon Place, Suite 250, San Ramon, CA 94583; e-mail: jaa@engeo.com

ABSTRACT

Sustainability analysis, or triple bottom line analysis, is increasingly recognized as a holistic approach when all the three pillars of sustainability (environmental, economic and social aspects) are equally incorporated into the decision-making process of a project. Currently, the tools for assessing the environmental and economic impacts are well established. On the contrary, the development of a quantitative tool to assess the social impacts has been particularly challenging because a multitude of subjective factors may vary among social entities depending upon the type of project assessed. In this study, a new tool called Social Sustainability Evaluation Matrix (*SSEM*) is developed and applied to two environmental remediation project sites. In both cases, remedial options were previously identified and assessed based on environmental and economic aspects. SSEM is an Excel-based tool comprising four social dimensions: (1) socio-individual, (2) socio-institutional, (3) socio-economic, and (4) socio-environmental. Under each dimension, several key areas are identified, and a scoring system is devised to quantify the extent of resulting social impacts. Scores for the identified key areas are summed under each social dimension, and a comparative assessment is performed to allow for more informed decisions about remedy selection, design, implementation, and mitigation as necessary. Overall, *SSEM* was found to be quite beneficial in assessing social sustainability of the selected remedial options in this study; however, it is important to incorporate an objective basis to the highest degree practicable. Also, when negative, substantive impacts are identified, mitigation efforts should be made to minimize or avoid the impact.

INTRODUCTION

The concept of sustainability is currently employed in a broad spectrum of multidisciplinary fields and has garnered significant interest among various

© ASCE 2014

professionals in the past couple of decades. The most widely accepted definition for sustainability to date originated from the United Nations World Commission on Environment and Development report (UN-WCED, 1987), also known as *Our Common Future* report or the Brundtland report, which refers to sustainability as: *"…development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* This definition is succinct and captures the essence of sustainability in a broader perspective. However, for planning and implementation purposes, more functional definitions that reflect specific goals have to be adopted. The United States Environmental Protection Agency (USEPA) formulated its own definition for sustainability (NRC, 2011 and USEPA, 2012). According to this definition, sustainability is "the continued protection of human health and the environment while fostering economic prosperity and societal well-being." For more practical applications, the concept of "three pillars", or "triple bottom line", of sustainability gained prominence, encompassing the environmental, economic and social measurables into evaluating the overall impacts of a project throughout its life cycle. From the 1980s until the mid-1990s, greater importance was given to evaluating the life cycle environmental impacts with less focus on the economic and social aspects. This scenario changed in the late 1990s, at which time roughly equal importance was given to the environmental as well as economic impacts of a project during its life cycle. The impact of civil engineering projects on human health and surrounding communities attracted equal attention during the design and implementation phases in the past decade with the aim of sustaining harmony and creating a positive impact for the society.

Sustainability indicators are measurable aspects of environmental, economic, or social systems that are useful for monitoring changes in system characteristics relevant to the continuation of human and environmental well-being (e.g., greenhouse gas emissions). On the other hand, sustainability metrics are measured values to quantify the resulting impacts from specific indicators and are based on tools developed to determine each metric for a specific study (e.g., LCA). The attributes of sustainability indicators can be formal, informal, objective, or subjective, and some of the characteristics of indicators are suggested to be SMART – Simple, Measurable, Accessible, Relevant, and Timely; and SPICED – Subjective, Participatory, Interpreted and communicable, Cross-checked and compared, Empowering, and Diverse and disaggregated (Roche, 1999). The most widely used indicators by the United Nations for quantifying sustainable development are classified under 12 different categories, which include poverty, population stability, human health, living conditions, costal protection, agricultural conditions, ecosystem stability, atmospheric impacts, generation of wastes, resource consumption, economic growth, and accessibility to information (UN, 2007).

The functional sustainability indicators for environmental remediation are well established along with metrics and tools to quantify the impacts considering the environmental and economic aspects (ITRC, 2011). However, social sustainability aspects received little attention. The definition of social sustainability was coined by Polese and Stren (2000), which led to the establishment of the following common ingredients for social sustainability (Colantonio, 2007):

- Meeting basic needs

© ASCE 2014

- Overcoming disadvantage attributable to personal disability
- Fostering personal responsibility, including social responsibility and regard for the needs of future generations
- Maintaining and developing the stock of social capital, in order to foster trusting, harmonious and co-operative behavior needed to underpin civil society
- Attention to the equitable distribution of opportunities in development, in the present and in the future
- Acknowledging cultural and community diversity, and fostering tolerance and,
- Empowering people to participate on mutually agreeable terms in influencing choices for development and in decision-making.

The social sustainability indicators should be developed keeping in mind these common ingredients (Colantonio, 2007). However, widespread ambiguity among remediation professionals still prevails with respect to adopting a unified approach for quantifying the social impacts and indicators of a project since metrics and tools for this purpose are scarce and challenging to devise.

The objectives of this study are: (1) to develop a matrix for assessing the social impacts (*SSEM*) of an environmental remediation project, (2) to devise a quantification tool to evaluate the metrics pertaining to project-specific goals and criteria, and (3) to demonstrate the applicability of the developed *SSEM* tool for two contaminated sites, the Indian Marsh Ridge Site (Chicago, IL) where near-surface soils are contaminated by heavy metals and polycyclic aromatic hydrocarbons (PAHs); and the Matthiessen and Hegeler Zinc Superfund Site (near LaSalle, IL) where near-surface soils are contaminated by heavy metals.

DEVELOPMENT OF *SSEM* TOOL

The sustainability framework developed by USEPA (NRC, 2011 and USEPA, 2012), which incorporates an integrated approach for sustainability evaluation, formed the basis of *SSEM* development in this study. In order to quantify the social aspects of sustainable remediation, it is critical to establish meaningful indicators that account for cross-functional aspects of the pillars of sustainability, i.e. socio-individual, socio-institutional, socio-economic and socio-environmental. *SSEM* is an Excel-based tool with several social dimensions and identified key measures, as presented in Table 1. These are comprised by 18 key measures for socio-individual impacts, 18 key measures for socio-institutional impacts, 11 key measures for socio-economic impacts, and 13 key measures for socio-environmental impacts.

The socio-individual and socio-institutional dimensions encompass indicators that pertain to overall impacts on standard of living, education, population growth, justice and equality, community involvement, and fostering local heritage. The socio-economic dimension comprises indicators pertaining to business ethics, fair trade and worker's rights. The socio-environmental dimension accounts for the consumption of natural resources, environmental management, and pollution prevention in all environmental media such as air, water, land and waste. The incorporation of all four social dimensions and their corresponding indicators into the *SSEM* tool is perceived

© ASCE 2014

to be best representative of the overall resulting social impacts through the entire life cycle of a proposed environmental remediation project. The developed *SSEM* is flexible and accommodates the use of additional key areas to facilitate project-specific application and quantification of the social impacts.

Table 1. Social dimensions and key theme areas included in the Social Sustainability Evaluation Matrix (*SSEM*)

Dimension	Key Theme Area
Socio-individual	Effect of proposed remediation on quality-of-life issues during and post-construction/remediation
	Crime
	Cultural identity and promotion
	Overall public health and happiness
	Population demographics (age, income)
	Gender equity
	Justice and equality
	Care for the elderly
	Care for those with special needs
	Degree to which post-remediation project will result in skills development
	Degree to which post remediation project will result in leadership development opportunities
	Enhancement of community/civic pride resulting remediation and post-remediation project
	Degree to which tangible community needs are incorporated remediation design
	Transformation of perceptions of project and environs within greater community
	Potential of post-remediation project to enhance cultural diversity in community
	Potential of incorporating newcomers to community
	Potential of remediation to foster better health through enhanced recreational opportunities
	Enabling knowledge management (including access to E-knowledge)
Socio-Institutional	Appropriateness of future land use with respect to the community environment
	Degree of land use planning fostered by proposed construction/remediation
	Involvement of community in land use planning decisions
	Enhancement of commercial/income-generating land uses
	Improvement and enhancement of market-rate housing stock
	Improvement and enhancement of affordable housing stock

© ASCE 2014

	Enhancement of recreational facilities
	Enhancement to the architecture/aesthetics of built environment
	Enhancement and participation of school system (i.e., new buildings) in community
	Enhancement and participation of new congregations and facilities in community
	Enhancement and participation of government institutions (i.e., new facilities) in community
	Degree of "grass-roots" community outreach and involvement
	Involvement of community organizations pre- and post-construction/remediation
	Enhancement of cultural heritage institutions within community
	Involvement and enhancement of community-based charitable organizations
	Incorporation of green and sustainable infrastructure into construction/remediation
	Enhancement of transportation system improvements
	Trust, voluntary organizations and local networks (also known as social capital)
Socio-Economic	Disruption of businesses and local economy during construction/remediation
	Employment opportunities during construction/remediation
	Employment opportunities post-construction/remediation
	Degree of project investment toward Local Business Entities (LBEs)
	Degree of project investment toward Disadvantaged Business Entities (DBEs)
	Post-construction/remediation 3rd party business generation
	Relative degree of increased tax revenue from Site Reuse
	Relative degree of increased tax revenue from nearby properties
	Degree to which green/sustainable or other "new economy" businesses may be created
	Degree of stimulated informal activities/economy
	Degree of anticipated partnership and collaboration with outside investors/institutions
Socio-Environmental	Remediation of naturally-occurring contaminants (i.e., naturally-occurring asbestos, radon)
	Remediation of anthropogenic contaminants at "chronic" concentrations
	Remediation of anthropogenic contaminants at "acute" concentrations
	Remediation of pervasive "economic poisons" or other pervasive conditions endemic in community
	Degree of protection afforded to remediation workers by proposed remediation

© ASCE 2014

	Degree of disruption (noise, truck traffic) from proposed remedial method to the surrounding neighborhoods
	Degree of contaminant removal/destruction vs. in-place capping or immobilization
	Degree of future characterization/remediation required by re-zoning or altered land use
	"Greenness"/sustainability of proposed remedial action
	Incorporation of green energy sources into remediation activity
	Restoration or impact to productive surface water or groundwater use
	Degree proposed remediation will affect other media (i.e., emissions/air pollution)
	Potential of future environmental impact (i.e., diesel exhaust from trucks)

A scoring system has been devised as shown in Table 2, with zero value for no impacts, +1 or +2 for positive impacts, and -1 or -2 for negative impacts in order to evaluate the metrics for sustainability indicators under all four social dimensions. A score is assigned for each key area, and the sums of scores for each dimension as well as the total score of all four dimensions are calculated and compared for various remediation options being considered, including the "no action" option. This tool provides a better understanding of the resulting social impacts under descriptive categories, which can facilitate the formulation of targeted action plans aimed at overall impact mitigation.

Table 2. Scoring System for *SSEM*

Score				
Positive Impact		No Impact or Not Applicable	Negative Impact	
Ideal	Improved		Diminished	Unacceptable
2	1	0	-1	-2

APPLICATIONS OF *SSEM* TOOL

The SSEM tool is applied to assess the social sustainability in addition to the environmental and economic sustainability aspects for two sites as detailed in this section.

Indian Ridge Marsh Site

Indian Ridge Marsh (IRM) is among the several degraded wetlands in the Calumet region of Chicago, Illinois proposed for remediation and redevelopment as part of the Calumet Open Space Reserve (COSR). A variety of contaminant types were identified within soils, groundwater, sediments, and surface water through several site assessments. The most prominent contaminants were semi-volatile organic compounds (SVOCs), volatile organic compounds (VOCs), heavy metals, and total petroleum hydrocarbons (TPH). Based on a comprehensive assessment of

© ASCE 2014

existing site conditions (geology and hydrogeology), types of media impacted, and the levels of risk posed to human health and the environment, a risk-based corrective action (RBCA) approach was employed to identify suitable remedial measures for this site in a previous study (Yargicoglu and Reddy, 2013). Green and Sustainable Remediation (GSR) tools, such as Green Remediation Evaluation Matrix (GREM), SiteWise^{TM}, and Sustainable Remediation Tool (SRT^{TM}) were employed for both qualitative as well as quantitative evaluation of sustainability aspects pertaining to applicable remedial technologies for the site. Two remedial alternatives were chosen for comprehensive analysis with detailed estimates of project metrics using SiteWise^{TM}, including: (1) phytoremediation coupled with enhanced bio-stimulation, and (2) excavation of contaminated soil. The results from this analysis clearly indicated that phytoremediation in conjunction with enhanced bio-stimulation was a more sustainable, remedial alternative as opposed to excavation of the contaminated soil from site. The major indicators used for the evaluation of sustainability metrics involved GHG emissions, total energy used, costing, final cost with footprint reduction, water impacts, NO_x, SO_x and PM_{10} emissions, topsoil consumption, and other metrics such as accident risk of fatality and injury, lost hours due to injury, and space consumed for disposal of hazardous and non-hazardous wastes. From the list of indicators mentioned, it is evident that a prior sustainability assessment was conducted with a higher priority given to environmental and economic dimensions, with less focus on the societal dimension.

The *SSEM* tool is applied to the Indian Ridge Marsh project to evaluate the social impacts of both remedial alternatives. Some reasonable justifications for the assigned scores in *SSEM* for the evaluation of metrics are as follows:

- With respect to the socio-individual dimension, the phyto-EB option was assumed to create a positive impact on quality-of-life issues since it involves the least disturbance of contaminated soil, limiting dust generation; and reduced generated traffic. The phyto-EB option can enhance the natural pride of the surrounding community and provide opportunities for recreation and development of new skills through knowledge enhancement as compared to the excavation and disposal option. Phyto-EB results in less site disturbance, enhances aesthetics, and may offer an attractive destination as compared to a site where excavation has resulted in a less aesthetically pleasing alteration of the land.
- Under the socio-institutional dimension, phyto-EB was assumed to create positive impacts by fostering future land use for community-based recreational purposes and improved impacts resulting from the enhancement of architecture/aesthetics of surrounding communities. Phyto-EB would foster greater positive participation from government, community organizations, voluntary organizations, and local networks. Excavation and disposal often results in a higher degree of negative responses from local and community organizations due to the potential health hazards during/post remedial activity.
- Under the socio-economic dimension, site remedy involving excavation and disposal resulted in the highest positive impact due to job generation and employment potential, both directly (employment directly associated with the

© ASCE 2014

remedial activity) and indirectly (enhanced economic activity in the community due to patronage of local businesses). Both impacts result in increased economic development of the surrounding community.

- Under the socio-environmental dimension, phyto-EB has higher positive impacts due to higher degree of protection to workers during/post remedial activities. Phyto-EB is an in-situ technology which avoids future impacts from emissions and roadway wear generated by large trucking loads during excavation and disposal; phyto-EB exhibits a greater degree of "greenness"; however, the downside is that the plants require a minimum of 5 growing seasons to effectively remediate the contaminant levels, while excavation and disposal is a much quicker alternative.

Results of the social sustainability assessment are shown in Figure 1. It should be noted that the net grand score for excavation and disposal option is zero. Overall, *SSEM* results indicate that the phytoremediation with enhanced bio-stimulation (phyto-EB) remedial option has the highest positive impact on the surrounding community as compared to the excavation and disposal option. It is also evident that if no remedial action were taken, negative impacts would result to the surrounding community and is thus considered to be the worst-case scenario.

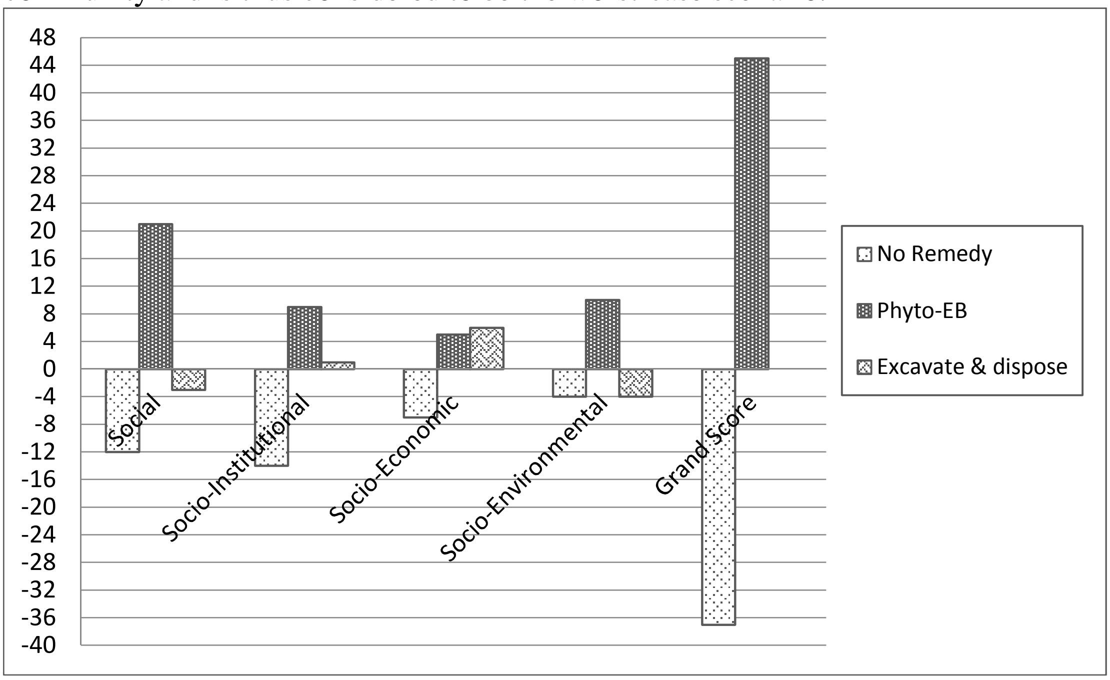


Figure 1. *SSEM* results for Indian Ridge Marsh site

Former Matthiessen and Hegeler Zinc Superfund Site

The Matthiessen and Hegeler Zinc smelting site located near Danville, Illinois was designated as a Superfund site in 2005 due to excessive contamination from heavy metals. Illinois EPA conducted comprehensive site assessments involving soil and sediment sampling within surrounding residential areas. Elevated zinc concentrations were detected in all samples, and cadmium and lead were elevated in

© ASCE 2014

all but one sample. Additionally, elevated levels of arsenic were also identified in certain areas of the smelter site. In general, the large surface area of the contaminated site, over 40 hectares (100 acres), posed a challenge for choosing appropriate remedial technologies. Two alternative treatment methods were evaluated for long-term sustainability – a conventional excavation, hauling and disposal program, and an in-situ remediation approach via solidification/stabilization (Goldenberg and Reddy, 2014). An inventory of materials required to remediate a constant depth of 0.6m of the contaminated soil throughout the 40-acre site was assumed for both remedial options to facilitate fair comparison between both options. A quantitative LCA was conducted using SimaPro (Version 7) to evaluate the environmental sustainability metrics using indicators such as global warming, air pollutants, eco-toxicity, smog, natural resource depletion, and water intake as well as human health impacts resulting from the generation of carcinogenic compounds. An economic sustainability analysis was also conducted in order to compare the costs incurred by the application of both remedial alternatives at the contaminated site. Based on the results obtained from SimaPro analysis and economic sustainability analysis, in-situ solidification/stabilization (in-situ S/S) was found to be the most sustainable remedial option for this project site. However, the comparative sustainability evaluation (Goldenberg and Reddy, 2014) seldom focused on the social aspects associated with the application of both the remedial alternatives.

The *SSEM* tool is applied to evaluate the resulting social impacts from both the remedial options evaluated for the zinc smelter site. Many of the socio-individual, socio-institutional, and socio-economic dimensional benefits cited in the Indian Ridge Marsh Site are identical to this case; in-situ S/S offers identical advantages in many cases compared to excavation for these dimensions. The justification for the scores assigned under the socio-environmental dimension in the *SSEM* tool as presented in are discussed below:

- The process of excavation and hauling incurs greater negative impacts due to increased truck traffic and roadway wear in the surrounding community, impacts from vehicular emissions, noise pollution and greater consumption of energy and fuel, which consequently results in negative scores for the extent of "greenness" pertaining to the application of this option.
- The use of in-situ S/S remedial option offsets excessive trucking and associated negative impacts; however, the use of excessive cement quantities in this technique can create a negative impact since the manufacture of cement is an energy-intensive process and can also generate toxic emissions such as mercury, acidic gases and particulate matter, which are considered to be toxic for human health. This issue can be addressed by incorporating recycled materials as a partial substitute for cement (for ex. slag-cement mixtures)

Figure 2 shows the results of *SSEM* results and these results indicate that in-situ S/S had the highest levels of positive social impacts in all four social dimensions evaluated as compared to the excavation and hauling option. Excavation and disposal was found to negatively impact the socio-environmental dimension and contributed to approximately equal positive impact as compared to in-situ S/S under all other social

© ASCE 2014

dimensions. The category of 'no remedy' option resulted in the highest level of negative social impact (Figure 2).

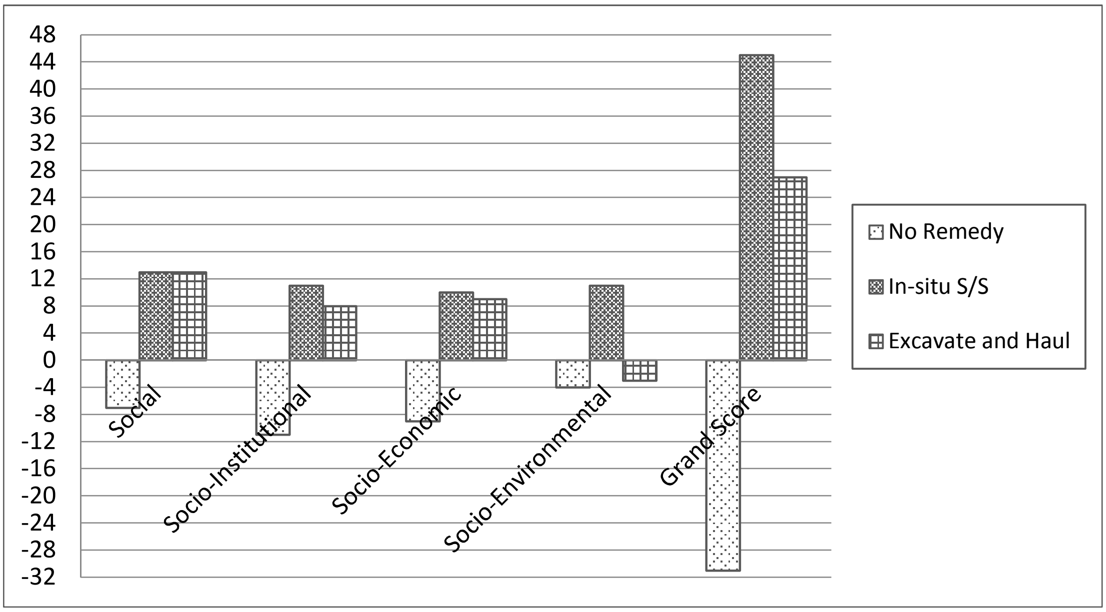


Figure 2. *SSEM* results for Matthiessen and Hegeler Zinc Superfund site

CONCLUSIONS

Indicators, metrics and tools are currently available and reasonably well established to quantify the environmental and economic aspects of sustainability. The development of the metrics as well as simple and practical tools to quantify the social sustainability of remediation projects has been identified as an urgent priority by sustainable remediation professionals. A social sustainability evaluation matrix (called as *SSEM*) has been developed in this study as a tool to identify key social issues and quantify their relative positive or negative impacts. It should be noted that social quantification is not a goal in or of itself; rather, it is a systematic process where a comparison and assessment can be made to allow for informed decisions on environmental remedy selection.

REFERENCES

Colantonio, A. (2007). "Social Sustainability: An Exploratory Analysis of its Definition, Assessment Methods, Metrics and Tools." EIBURS Working Paper Series on Measuring Social Sustainability: Best Practice from Urban Renewal in the EU, Oxford Brookes University, Oxford, UK.

Goldenberg, M., and Reddy, K.R. (2014). "Sustainability Assessment of Excavation and Disposal versus In-situ Stabilization of Heavy Metal Contaminated Soil at a Superfund Site in Illinois." Geotechnical Special Publication 234, Proc. of the Geo-Congress 2014, Abu-Farsakh et al. (Eds.), American Society of Civil Engineers, Reston, VA.

© ASCE 2014

ITRC (Interstate Technology & Regulatory Council) (2011). "Green and Sustainable Remediation: A Practical Framework." GSR-2, Washington, D.C.

NRC (National Research Council) (2011). "Sustainability and the U.S. EPA." The National Academies Press, Washington D.C.

Polese, M., and Stren, R.E. (2000). "The Social Sustainability of Cities: Diversity and the Management of Change." University of Toronto Press.

Roche, C. (1999). "Impact Assessment for Development Agencies: Learning to Value Change." Oxfam/Novib Publisher, Oxford, UK.

UN-WCED (United Nations World Commission on Environment and Development) (1987). "Our Common Future." Oxford University Press, Oxford, UK, 416p.

UN (United Nations) (2007). "Indicators of Sustainable Development: Guidelines and Methodologies." United Nations, New York.

USEPA (United States Environmental Protection Agency) (2012). "A Framework for Sustainability Indicators at EPA." EPA/600/R/12/687, National Risk Management Research Laboratory, Office of Research and Development, Washington, D.C.

Yargicoglu, E.N., and Reddy, K.R. (2013). "Green and sustainable remediation of contaminated Indian Ridge marsh site in Chicago, USA." Proc., Coupled Phenomena in Environmental Geotechnics (CPEG), Manassero et al. (Eds.), Taylor & Francis Group, London.

© ASCE 2014

SUSTAINABILITY ISSUES IN THE CALIFORNIA DELTA

Lawrence H. Roth, P.E., G.E., D.GE, F.ASCE

Principal Engineer, ARCADIS U.S., Inc., 101 Creekside Ridge Court, Suite 200, Roseville, California 95678; email: larry.roth@arcadis-us.com

ABSTRACT

The California Delta is the heart of the state's water system and ground-zero in the search for sustainable solutions to problems of water supply, habitat restoration, and flood risk reduction. For years, the Delta ecosystem has been in decline threatening species collapse and water supply reliability. In addition, people and infrastructure in the Delta are dependent on levees for flood protection, levees that are susceptible to failure from earthquakes, seepage, and overtopping. Catastrophic levee failure would be devastating to people, water supply, infrastructure, and the environment. Water supply, habitat restoration, and flood risk reduction are interdependent systems in the Delta and our current ways of managing them are neither efficient nor sustainable. To implement new water infrastructure, restore habitat, and reduce flood risk, we must find solutions that meet not only today's needs, but the needs of future generations as well. A sustainable water supply and a sustainable Delta depend on a systems approach to achieve resiliency, efficiency, and smooth integration with other infrastructure systems; on sound decision-making to manage risk and adapt to change; and on meeting the state's coequal goals of water supply reliability and ecosystem restoration.

INTRODUCTION

Since the days of the Gold Rush, California has benefitted from making sound investments in infrastructure, particularly in the state's vast, complex water systems. California's infrastructure investment has promoted dramatic growth in population and in the state's economy. For over 100 years our water infrastructure has taken care of us even though lately we have neglected it by deferring maintenance and needed improvements. Building and maintaining water infrastructure to meet California's growing population and economy while preserving and enhancing its environment is generally thought to be the state's most urgent challenge.

Building new and retrofitting old water systems for the 21st century requires that we embrace sustainable solutions so that we not only meet current needs, but that we also meet the needs of future Californians. Bill Wallace, author of *Becoming Part of the Solution: The Engineer's Guide to Sustainable Development*, describes how we can design, build, and operate infrastructure systems that meet the test of sustainability. He identifies two critical contributions to sustainability (Wallace 2014). The first is the performance contribution, or did we do things right? This may be the easy part. For example, have we pushed the boundaries of sustainable performance? Have we

© ASCE 2014

raised the bar regarding our knowledge of sustainability? Have we achieved what is reasonable within the realm of technical feasibility and acceptable risk?

We have learned, however, that doing things right is not sufficient to be truly sustainable. We must also meet Wallace's second criterion, the pathway contribution, or doing the right things. This may be the hard part. To be on the right path, we must consider how proposed improvements to infrastructure align with the principles of sustainability, how they will affect related systems, how they can be adapted for changing conditions, and how we can be sure that they will not adversely impact future generations.

Achieving sustainability in California's water infrastructure depends on doing things right, and on doing the right things. We can set the direction for achieving sustainability by: 1) adhering to guiding principles promulgated by the American Society of Civil Engineers (ASCE 2009) to help us do things right; and 2) paying heed to California's constitution and the coequal goals (Delta Reform Act 2009) to help us do the right things. Nowhere is application of this guidance more pressing than in the California Delta, the heart of the state's water infrastructure.

THE CALIFORNIA DELTA

The California Delta, generally bound by Sacramento to the north, by Stockton to the south, and by Antioch to the west, is the confluence of two of the state's major rivers, the Sacramento and the San Joaquin, and is the largest estuary on the west coast of the Americas. Together, the watersheds for these river systems cover just over one-third of California, an area of usually abundant rain and snow in an otherwise mostly arid state. The Delta is a rare inverted delta system where the tributary rivers and streams coalesce before flowing through the Carquinez Strait into San Francisco Bay and out to the Pacific Ocean.

Before European settlers arrived in California in the 1700s, the Delta was a vast estuary and wetland complex with over 540 square miles (140,000 ha) of freshwater wetlands and 380 square miles (98,000 ha) of salt marsh that provided rich and productive habitat for more than 500 species of fish and wildlife. The pre-1800s Delta, often referred to as the American Serengeti, flooded frequently creating a vast, seasonal inland sea.

During and following the Gold Rush, its rich potential for agriculture was exploited and today's Delta is largely man-made, characterized by an extensive levee system to stave off flooding. Today, less than five percent of its former salt marsh and wetland habitat remains. The Delta comprises over 50 major islands and an intricate network of waterways. The islands are surrounded by 1,100 miles (1,770 km) of levees that vary in quality from adequate to fragile. A century ago the land surface was near sea level. Years of levee building and farming have caused consolidation, compaction, and oxidation of the rich peat and organic soils, and the islands continue to subside. Most land is now as much as 20 feet (6 m) below sea level, and the levees function as dams with water against them year-round.

© ASCE 2014

Much of the rain and snow that falls in northern California and the Sierra Nevada flows to the Delta through the Sacramento-San Joaquin River systems. Some of this flow is captured in storage reservoirs for later release. Some flow is diverted for urban and agricultural use before it reaches the Delta. When the remaining water reaches the Delta, some is diverted through Delta waterways to large pumping plants in the south Delta where it is sent west to cities in the San Francisco Bay area, and south to urban areas of southern California and the rich farmland of the San Joaquin Valley.

That 25 million people and over two million acres of farmland rely on the Delta as a source of fresh water is testament of its critical importance to the state's water infrastructure. In addition, the Delta is home to one-half million people, supports a strong agricultural-based economy, and is highly valued for its recreational opportunities and its fish and wildlife habitat. Critical infrastructure systems (water supply facilities, highways, railroads, natural gas pipelines, power lines, etc.) that are important to the entire state crisscross the Delta.

For many years, the ecosystem of the Delta has been in dramatic decline and several species face extinction if steps are not taken soon. In addition, the Delta and its people and infrastructure are at serious risk from floods. The flood management system is critically dependent on Delta levees, which are susceptible to failure from ground shaking, overtopping, and seepage. Levee stability is made worse by continuing subsidence and sea level rise. Catastrophic levee failure would be devastating to people, property, water supply, infrastructure, and the environment.

OUR SUSTAINABILITY CRISIS

The *California Water Plan* (2009) recognizes that the water infrastructure that has gotten us to where we are today will not meet our future needs. The plan, which is in the process of being updated, identifies infrastructure strategies for water systems to meet the needs of our growing population. Those strategies include providing better stewardship of the resource by reducing demand, improving operations, increasing supply, and enhancing water quality.

Because of past performance, people assume that water will always be there and that supply will always be adequate. Improvements to our water infrastructure will be expensive, and the new infrastructure we build should last a long time, so it must be done right. The framers of California's constitution wrote that water is a public trust. Today we would say that our water use must be sustainable, that it must not only meet today's needs, but we must also guarantee that it will meet the needs of future generations.

Fortunately, fresh water is a renewable resource, unlike many other natural resources such as fossil fuels. Though renewable, it is not increasingly available, nor even constant. In fact, the 2009 state water plan states that California faces one of the most significant water crises in its history, which is today exacerbated by devastating drought. The current drought underscores the need to deal with uncertainty in long-term water supplies caused by increasing demand, environmental stressors, and climate change. In addition, the scale of groundwater overdraft in California

© ASCE 2014

demonstrates our failure to manage the system in a sustainable way (California DSC 2013).

We are also dealing with increased flood risks as people move into flood-prone areas bound by ageing levees. Climate change is expected to bring warmer winters with more precipitation falling as rain instead of snow. This is likely to cause more severe flooding in inland valleys including the Delta, which also faces rising sea level. The state's flood risk reduction infrastructure is not only ageing, but it must be upgraded to meet higher safety standards. New annual investments of $800 million to $1 billion are needed to improve the system, which means doubling the money currently spent on local flood management (Hanak 2014).

Ecosystems are declining because our watersheds are in poor health – we have lost suitable habitat, there is competition from invasive species, and we have pursued aggressive water operations that divert much-needed water from fish. To mitigate the damage from past actions, we need to spend an additional $400-700 million each year to provide habitat conservation, to protect threatened and endangered species, and to restore the environment. Half of this investment is needed in the Delta and greater Sacramento–San Joaquin watershed (Hanak 2014).

In addition, we face growing water quality problems in both our surface and groundwater, and we must deal with the ageing infrastructure systems that collect, store, and move water around the state, systems that are weakened by lack of timely maintenance.

It's no surprise that the state water plan says we are in a water crisis. Though he was referring to global water concerns, Dr. Richard Wolfenden of the University of North Carolina could have been describing the situation in California when he said: "I think our relationship to water is going to be one of the deciding things of the next century. I don't think water's in any trouble. But we might be" (Fishman 2011).

California's population has more than doubled in the past 50 years, and may nearly double again in the next four decades. This phenomenal growth poses difficult questions: What will happen if we fail to address our crumbling infrastructure and our threatened ecosystems? What will land use – cities, farms, and ecosystems – look like in the future? How will climate change impact sea level and weather? The demands of 21st century California will most certainly accelerate resource depletion, further damage the environment, strain institutions, and exacerbate conflict.

The critical challenge we face is making our water supply sustainable while continuing to improve our economy and our quality of life. Surprisingly, we seldom hear the term "sustainable" in current debates about water. How can we be sure that these strategies will lead to a sustainable future?

DELTA SUSTAINABILITY

In 2009 the California Legislature recognized those concerns and passed the Delta Reform Act, which established the coequal goals as state policy – twin goals of providing a more reliable water supply and protecting, restoring, and enhancing the

© ASCE 2014

Delta ecosystem. It mandates that the coequal goals be achieved in a manner that protects and enhances the unique natural resource, cultural, agricultural, and recreational values of the Delta as an evolving place. In addition, the legislation requires that improved regional supplies, conservation, and water use efficiency be implemented to reduce reliance on the Delta in meeting future water supply needs (Delta Reform Act 2009).

Because the Delta is in crisis, it is currently the focal point of several studies that have many issues in common, in particular water supply, ecosystem restoration, and flood risk management. The plans, some complete and others nearing completion, have implementation costs anticipated to be tens of billions of dollars:

- The Delta Stewardship Council is an independent state agency charged with furthering achievement of the coequal goals. The Councils' *Delta Plan* recommends policies and priority actions to improve statewide water supply reliability, and to protect and restore a healthy Delta ecosystem, all in a manner that preserves and enhances the unique characteristics of the Delta as a place (California DSC 2013).

- The *Bay Delta Conservation Plan* (BDCP) by the California Department of Water Resources (CA DWR), the U.S. Bureau of Reclamation (USBR), and state and federal water contractors, is focused on water conveyance and ecological restoration (California DWR 2013a). BDCP includes new water intakes on the Sacramento River in the north Delta, twin 44-foot (13.4 m) diameter water conveyance tunnels 35 miles (56 km) long, and 140,000 acres (57,000 ha) of ecosystem protection and enhancement. The preferred BDCP alternative includes a through-Delta component of water delivery, which will require levee strengthening to improve reliability and resilience to floods and earthquakes.

- The *2012 Central Valley Flood Protection Plan* guides the state's participation in managing flood risk along the Sacramento and San Joaquin River systems (California DWR 2011). The plan proposes a systemwide investment approach for integrated flood management in areas currently protected by the State Plan of Flood Control.

- CA DWR has also been working to develop a framework to guide state investments to improve integrated flood management specific to the Delta (California DWR 2013b). The framework, currently in draft form, is intended to provide clear rationale for helping make difficult choices about investing limited state funds in flood risk reduction projects in the Delta. While CA DWR states that the framework was created to support decisions regarding investments that will likely be made in a number of large-scale planning efforts underway in the Delta, there is no clear mechanism to link with these other efforts.

- The Delta Protection Commission's *Economic Sustainability Plan for the Sacramento-San Joaquin Delta* recommends improved flood management and levee strengthening for enhanced resilience saying that levee investment is essential to economic sustainability in the Delta and is the most cost-effective strategy to achieve water supply reliability (California DPC 2012).

© ASCE 2014

- Finally, in early 2014, the state released an over-arching plan to guide policy- and decision-making regarding the state's water resources. The *California Water Action Plan* (2014) focuses on challenges to effectively managing the state's water resources. The challenges echo those included in the 2009 *California Water Plan*, with renewed emphasis on issues of water scarcity and drought. The 2014 plan identifies actions deemed critical for the Delta: achievement of the coequal goals; protecting and restoring important ecosystems; and increasing flood protection.

Most of the various plans affecting the Delta include recommendations to strengthen levees noting that habitat restoration can be effectively integrated with flood risk reduction through construction of new, hardened setback levees to widen channels for more efficient flood flow. The plans also note, however, that without attention, periodic levee failure is certain and that it will not be cost-effective to repair each failure as it occurs. Cascading levee failures will eventually destroy the Delta as we know it. As part of the effort to achieve a sustainable Delta, levees must soon be hardened for improved resilience, which can also lead to opportunities for habitat creation, to more effective flood management, and to a more reliable water supply.

THE PERFORMANCE CONTRIBUTION

The performance contribution means doing things right. Using lessons learned from the flooding of New Orleans during Hurricane Katrina, ASCE identified four guiding principles that can help ensure public safety, health, and welfare (ASCE 2009). The guiding principles inform decisions, drive actions, and align behaviors necessary to achieve satisfactory performance of critical infrastructure systems.

ASCE intended the guiding principles to be foundational to the first canon of its code of ethics (ASCE 2014): *Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties*. Following Katrina, the emphasis was on the first part of the canon – public safety, health, and welfare. The guiding principles, however, are also foundational to sustainability. Specifically, they provide guidance for the performance contribution, or doing things right.

What are the guiding principles? First, use a systems approach to plan, design, construct, and operate critical infrastructure systems to be resilient and fully integrated with other interdependent systems. Second, quantify, communicate, and manage risk so that critical infrastructure will meet its service expectations and so that end-users and the public can make good decisions about the consequences of infrastructure failure. Third, exercise sound leadership, management, and stewardship in decision-making processes regarding critical infrastructure. Finally, continuously adapt critical infrastructure in response to changing conditions, new knowledge, and improved practice.

Recognizing that both public and private sectors have dismal records of delivering large infrastructure projects on time and in budget, Flyvbjerg (2009) explains executive disasters two ways. First, delusion occurs when a plan is developed using the best view of the issues at hand as well as optimistic forecasts, which often lead to

© ASCE 2014

underestimating costs, overestimating benefits, or both. Second, deception, which may be unintentional, can occur because of differences in risk tolerance, uneven information among parties, self-interest, or lack of accountability.

To avoid executive disaster, Flyvbjerg says delusion can be overcome by taking the outside view, while deception can be managed by ensuring accountability and transparency. According to ASCE, bringing in independent experts, or independent peer review, can ensure the outside view is taken, can foster transparency, and can trigger accountability. ASCE recommends external peer review whenever performance is critical to public safety, health, and welfare; when reliability is critical; or when there is no redundancy in design (ASCE 2007).

THE PATHWAY CONTRIBUTION

The pathway contribution, doing the right thing, is difficult to define and even more difficult to achieve. Wallace (2010) identifies three major factors in the pathway contribution: community, compatibility, and knowledge. In the community factor, sustainable infrastructure systems align with community goals, make good use of community resources, and are seen as fair and equitable. In the compatibility factor, sustainable infrastructure fits with existing systems and institutional capacity. In the knowledge factor, building and maintaining sustainable infrastructure systems creates knowledge as it advances our understanding of sustainability.

To achieve a sustainable water supply, the pathway contribution represents an enormous challenge. In our case, the community for water is the entire state so community issues, resources, and notions of fairness and social equity encompass all of California. Water is integral to all of our economic, social, political, and environmental systems, and required changes for sustainability will stress our institutions in ways not seen before. We must reduce demand, improve operations, increase supply, enhance water quality, manage flood risks, restore ecosystems, and push the envelope of our knowledge and understanding to be successful.

The long-standing constitutional principles of public trust and reasonable use provide a concrete basis for mandating a sustainable water future for the state. The public trust doctrine means that natural resources such as rivers, wetlands, and fish and wildlife are owned by the public – the community of California – and are held in trust for current and future generations. As a public trust resource, the reasonable use doctrine requires that water be used in ways that are appropriate, fair, and sensible.

The recently added notion of coequal goals is aimed at ensuring water supply reliability and preserving and restoring the ecosystem (Delta Reform Act 2009). Thus the requirement for sustainability is fixed not only in common sense, but also in both the state’s constitution and in the legislatively mandated coequal goals.

HOW ARE WE DOING?

In short, not well. We are not following the guiding principles for the performance contribution to sustainability, doing things right. We are in peril of failing to achieve satisfactory performance of critical water infrastructure systems, which jeopardizes a

© ASCE 2014

sustainable future for both the Delta and water supply in California.

The Delta is not being treated as a complex system that is interdependent with many other systems, a critical shortcoming. None of the many plans described earlier stipulate interaction with other plans despite obvious overlap. The *California Water Action Plan* (2014) falls short of mandating a systems approach. That water supply, ecological restoration, and flood management are being pursued independently with little apparent interaction on common issues or recognition of interdependency is surprising. Or, maybe not; as the *Delta Plan* observes: "Governmental institutions have reacted to each crisis [*in the Delta*] predictably, often treating individual problems rather than taking a systemwide approach. Over the years, dozens of agencies, task forces, and working groups have been created in a series of sometimes overlapping efforts to find the right combination of leadership and collaboration – incentives and regulation – to provide clean reliable water, protect our environment, and reduce the risk of flooding" (California DSC 2013). Regrettably, this statement rings true today.

Despite plans requiring massive spending on infrastructure and ecosystem improvements, we do not know how much we will reduce risks stemming from water supply disruption, from floods, or from continued ecosystem deterioration. Risks that are not understood cannot be managed, and the consequences cannot be effectively communicated to those most affected. On the other hand, if we do nothing, we face near-certain disruption to water supply; flood damage and loss of life; and ecosystem collapse.

Leadership and management are compromised in the Delta where governance is distributed across six counties and the CA DWR and USBR operate state and federal water supply systems. The U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the California Department of Fish and Wildlife provide stewardship for Delta ecosystems. CA DWR, the U.S. Army Corps of Engineers, and reclamation districts oversee flood management infrastructure in the Delta. In addition, local agencies, water contractors, environmental groups, and a host of activists and interested stakeholders influence short- and long-term decision-making. No one or no entity is in charge – no one can say, "The buck stops here."

Despite a good faith effort to account for the effects on climate change, we are approaching infrastructure systems in the Delta the same way we always have – by failing to adapt to changes driven by water supply demands, by population growth, by ecosystem deterioration, by changing demographics and land use, and by lessons learned elsewhere. Furthermore, most of the planning is faith-based – the belief is that improvements will work exactly as predicted without incorporating provisions for contingencies or back-up plans.

Despite the critical importance of water supply, ecosystem restoration, and public safety in the Delta, no independent peer review has been undertaken to ensure transparency and accountability. We remain vulnerable to executive disasters caused by deception and delusion as described by Flyvbjerg, in particular to the vagaries created by underestimated costs and overestimated benefits.

© ASCE 2014

In addition, we are not ensuring the pathway contribution, doing the right things. The coequal goals (Delta Reform Act 2009) call for "Protecting, restoring, and enhancing the Delta ecosystem" (Delta Reform Act 2009). Yet, there is no guaranteed stream of funding for the ecosystem restoration in any of the plans. For example, if BDCP is approved as currently structured, water supply improvements, with assured funding from the water contractors, can be built. However, without the assurance of future bond money or funding from the legislative, little restoration will take place, and the coequal goals will not be attained (California DWR 2013a).

The coequal goals also call for "Providing a more reliable water supply *for California*" (emphasis added). This means that reliability should be statewide, not favoring a particular region or type of user. By definition, a sustainable water supply is a reliable water supply; however, a water supply that is reliable only for those it serves while neglecting the needs of others is not a sustainable supply. Unfortunately, the current BDCP provides reliability only for south-of-Delta users (California DWR 2013a).

Finally, we are not being guided by the constitutional tenets of public trust and beneficial use. Over the past 100 years, we developed a well-engineered water infrastructure system for California based on one important thing – plentiful supply. We overcame the challenge of collecting the water where it was when it was wet, storing it for use, and moving it to where it was needed when it was dry. Our method of allocating water, our water rights system, was patterned after the riparian rights system developed far away and long ago in England and the eastern U.S.

The system of water rights may have been satisfactory when there was enough water to meet demand. When there is not enough water, however, we must implement a fair means to allocate a scarce resource, a resource that will be in higher demand in the coming years. Today, if someone or something gets more water, then someone or something must get less. Since water is a public trust and no one owns the resource – or, rather we all own it – how should water be allocated for beneficial and sustainable use?

There may be many ways to design and implement a water economy to govern allocation of a scarce resource in the future, a water economy that is both fair and sustainable. A sustainable water economy must meet at least two criteria for beneficial use. First, there must enough water to preserve a stable and healthy resource. Next, there must be enough water to meet basic human needs for health and quality of life. The water that remains, which could be a substantial portion of the resource, can then be allocated based on market-driven forces, the laws of supply and demand.

Designing and implementing a new water economy that provides for environmental sustainability, for satisfying basic human needs, for growing our economy, and for ensuring our quality of life today and in the future is a non-trivial exercise. It requires recognizing that our current way of managing water is neither efficient nor sustainable; it requires embracing the constitutional concepts of public trust and reasonable use, employing the new concept of coequal goals, and applying them to

© ASCE 2014

meet today's realities; and it requires re-thinking equity and fairness regarding water in our social, political, and economic institutions.

CONCLUSION

Our water supply is finite, and we are faced with growing population, climate change, and the need to protect and restore our environment, particularly in the California Delta. Previous generations of water planners and engineers conceived and built our water infrastructure to be an enabler for our current quality of life. In the 21st century, we must design, build, and operate our water infrastructure as a means to a sustainable future. Our resources are too valuable to squander.

A sustainable water future means water supply reliability, continued quality of life, economic vitality, a stable environment, and a thriving ecosystem. To achieve the performance contribution to sustainability, we must use a systems approach, effectively manage risk, exert strong leadership, adapt to change, and employ open and transparent processes. To achieve the pathway contribution, we must be guided by the doctrines of public trust and beneficial use to accomplish the coequal goals. We build infrastructure to last a long time. If we don't do the things right, and we don't do the right things, the infrastructure we build may last a long time, but it will not be sustainable. If we don't build it to be sustainable now, it will fall on the next generation to make it right – if they get the chance.

REFERENCES

American Society of Civil Engineers (ASCE). 2009. *Guiding Principles for the Nation's Critical Infrastructure*. American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, Virginia 20191.

American Society of Civil Engineers (ASCE). 2007. *The New Orleans Hurricane Protection System: What Went Wrong and Why*. American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, Virginia 20191.

American Society of Civil Engineers (ASCE). 2014. *Official Register*. American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, Virginia 20191.

California Department of Water Resources (California DWR). 2011. *2012 Central Valley Flood Protection Plan, Public Draft*. December 2011. State of California, Department of Water Resources, 1416 Ninth Street, Sacramento, California 95814.

California Department of Water Resources (California DWR). 2013a. *Bay Delta Conservation Plan, Draft Environmental Impact Report/Environmental Impact Statement*. December 2013. State of California, Department of Water Resources, 1416 Ninth Street, Sacramento, California 95814.

California Department of Water Resources (California DWR). 2013b. *FloodSAFE: A Framework for Department of Water Resources Integrated Flood Management Investments in the Delta and Suisun Marsh*. DRAFT, September 24, 2013. State of California, Department of Water Resources, 1416 Ninth Street, Sacramento, California 95814.

© ASCE 2014

California Water Action Plan (2014). California Natural Resources Agency, California Department of Food and Agriculture, and California Environmental Protection Agency. January 22, 2014. State of California, Natural Resources Agency, 1416 Ninth Street, Sacramento, California 95814.

California Water Plan (2009). State of California, Department of Water Resources, 1416 Ninth Street, Sacramento, California 95814.

Delta Reform Act. 2009. Division 35, Sacramento-San Joaquin Delta Reform Act of 2009, Part 4, Comprehensive Delta Planning. State of California Water Code.

Delta Stewardship Council (California DSC). 2013. *The Delta Plan*. State of California, Delta Stewardship Council, 980 Ninth Street, Suite 1500, Sacramento, California 95814.

Economic Sustainability Plan for the Sacramento-San Joaquin Delta. (California DPC). January 19, 2012. State of California, Delta Protection Commission, 2101 Stone Boulevard, Suite 210, West Sacramento, California 95691.

Fishman, Charles. 2011. *The Big Thirst*. Free Press, 1230 Avenue of the Americas, New York, New York 10020.

Flyvbjerg, Bent, Garbuio Massimo, and Dan Lovallo. 2009. *Delusion and Deception in Large Infrastructure Projects: Two Models for Explaining and Preventing Executive Disaster*. California Management Review, Vol. 51, No.2, Winter 2009. UC Press Journals Division, 2000 Center Street, Suite 303, Berkeley, California 94704.

Hanak, Ellen, Brian Gray, Jay Lund, David Mitchell, Caitrin Chappelle, Andrew Fahlund, Katrina Jessoe, Josue' Medelli'n-Azuara, Dean Misczynski, James Nachbaur, and Robin Suddeth. 2014. *Paying for Water in California*. Public Policy Institute of California, 500 Washington Street, Suite 600, San Francisco, California 94111.

Wallace, William A. 2010. Personal Communication. Wallace Futures Group, 1400 Overlook Drive, Steamboat Springs, Colorado 80487.

Wallace, William A. 2014. *Working to Engineer Infrastructure Resiliency in a Changing Operating Environment*. Geo-Characterization and Modeling for Sustainability, 2014 Geo-Congress of the Geo-Institute of ASCE, 1801 Alexander Bell Drive, Reston, Virginia 20191.

© ASCE 2014

Business Sustainability Requires Ethics

Sarah Hansen[1] and Peter Beukema[2]

[1]AMEC Environment and Infrastructure, Inc, 1075 Big Shanty Road, Kennesaw, Georgia 30144, PH +99(0) 1 770-421-3306, Fax +99(0) 1 770-421-3486, email: sarah.hansen@amec.com

[2] AMEC Environment and Infrastructure, Inc., 3300 Merrittville Hwy, Thorold ON Canada L2V 4Y6, PH +1.905.687.6616, email: peter.beukema@amec.com

Abstract

We cannot simply "flip the switch" and move from fossil fuel-based power to renewable power as many would like to believe. Sustainability is an evolution, not a revolution. The global community has developed a reliance on fossil fuels and many other non-renewable commodities including precious metals and other minerals provided by the earth. These natural resources are enablers in today's society in that they are necessary to fuel our lifestyle and quality of life. Globally, the result is a continued depletion of natural resources; thus, if not arguably, increasingly affecting our ability as a society to ensure the availability of natural resources for future generations. Therefore, while we continue to consume natural resources we have to hope and anticipate that our future generations will continually evolve sustainably.

Businesses drive the world economy and while governments can pass legislation for standards and requirements, ethical behavior cannot be legislated. However, it is clear that once unethical behavior is uncovered, the consequences to an organization for its unethical behavior can be severe, but by then the damage is already done and difficult, if not impossible, to undo.

The Code of Ethics that a business adopts determines and shapes its ethical practices and it is the resulting culture and attitudes of its employees that maintain its reputation. Although founded in common principles, each business will adopt a unique ethical code. Arguably, it is, at least in part, through the ethical decisions that engineering companies achieve the Social License to Operate (SLO) that drives sustainable development locally, regionally, and globally.

In this paper we will take a look at ethics and the social license that businesses, specifically engineering companies, are adopting to guide the sustainability evolution and the consequences (intended and unintended) of those paths.

© ASCE 2014

Sustainability as an Evolution

Being sustainable and contributing to sustainable development (locally, regionally or globally) means something different to practically everyone and consequently is very much context-specific, linked to what is valued (individually, culturally, professionally, politically). The insatiable societal appetite for material goods, personal modes of transportation, luxury residences, energy, etc. is perhaps the reason that the sustainability evolution is taking so long. Education and awareness of our societal predicament is being shrouded by the wants and not necessarily the needs hence, justifying the continued exploitation of the environment and people.

This context-specific application of sustainability has lead to numerous definitions (20 million hits on a Google search of "sustainability definition"). The authors acknowledge the American Society of Civil Engineers (ASCE) definition of sustainability which states "*sustainability is a set of environmental, economic and social conditions in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality or the availability of natural resources and ecosystems.*" (ASCE, 2009)

With this definition in mind, it is safe to say that as a society we have a long way to go. The engineering/scientific community, governments, academia, non-government organizations (NGOs) and society at large all have a vested interest and roles to play. Collectively everyone can contribute by conserving our resources and looking for ways to improve the social and environmental conditions within our communities. Every day, whether at home, at work or out in our community we all make choices which affect the future, however, it is the engineering and scientific communities which clearly have a great opportunity, which some might characterize as an obligation, to take a leadership role in sustainable development. If, as a society, we are to evolve from our current state to a sustainable society with *"…the capacity and opportunity to maintain and improve its quality of life indefinitely…"* (ASCE, 2009), innovation and discovery through engineering and science will be key.

History has repeatedly demonstrated there will be times of innovation and discovery followed by uptake and societal integration. For example, the discovery, harnessing, generation, and distribution of electrical energy enabled society to advance, resulting in an improved quality of life. Much of this was possible with good engineering and possibly occurred well before the consequences were understood. The consequence and downside is that with the use of electrical energy (and despite the societal benefits) came the increasing reliance on, and depletion/exploitation of, fossil fuels and other natural resources. Consistent with the principles described in the *"Tragedy of the Commons"* (Harden, 2008), one of the unintended consequences of producing

© ASCE 2014

electrical energy from fossil fuels has been the impact to air quality and increased heath affects (e.g. asthma, respiratory illness, etc.). Pressure from affected populations (the voice of the people) resulted in governmental regulations and enactment of air quality standards intended to protect human health and the environment, by maintaining air quality at levels deemed acceptable. It was engineers and scientists who played a significant role in designing and implementing technologies to measure, analyze and achieve these standards. In addition, today it is the engineers and scientists in both the public and private sectors that are exploring and developing renewable energy options that reduce our reliance on fossil fuels and conserve our natural resources.

The pace of this sustainability evolution can be modeled (at least qualitatively) and is influenced in part by the societal appetite or the "wanting" of goods and services. Another factor controlling the pace of the sustainability evolution is the opportunity that comes through vision, which is realized through innovation and discovery. There is no question that innovation and discovery require investment, such that the greater the potential return on the investment the greater the influence on the pace of the sustainability evolution.

The pace of the sustainability evolution can be characterized by adapting the Beckhard-Harris Change Model (D x V x F > R) where: D = the dissatisfaction with the status quo; V = vision; F = first steps; R = resistance to change (Beckhard and Harris, 1987).

Applying this change model to sustainability - the pace of the sustainability evolution will be maximized when:

- D = globally as a community we recognize that continued exploitation of people and the environment to feed our "wants" is unacceptable and there exists a willingness to search for more sustainable alternatives;
- V = there are recognized opportunity drivers in achieving a shared vision expressed consistently across the globe (this is where a common definition for sustainable development is critical);
- F = progressive actions (Plan) funded through investment that over time reduce the exploitation of people and the environment (the Plan is the roadmap for the sustainability evolution);
- R = society is aware of the consequences of not acting sustainably, trusts those guiding the sustainable path, believes that change is occurring and ultimately accepts change.

© ASCE 2014

As engineers and scientists, our contribution to the sustainability evolution is through the development and implementation of new technologies and practices that will enable society to evolve to the point where it is able to "…*maintain and improve its quality of life indefinitely*…" (ASCE, 2009). In applying the change model to the sustainability evolution, we recognize that achieving a sustainable future is rooted in continuous improvement and that perhaps the best we can do is to accept that the pace of the sustainability evolution will be controlled/influenced by those factors identified.

Figure 1 depicts the sustainability evolution as a continuous improvement process in which business, government, and society each share a leadership role in advancing sustainability. In addition, it is the efforts of scientists and engineers as members of each of these communities that have an obligation and ability to advance the sustainability evolution.

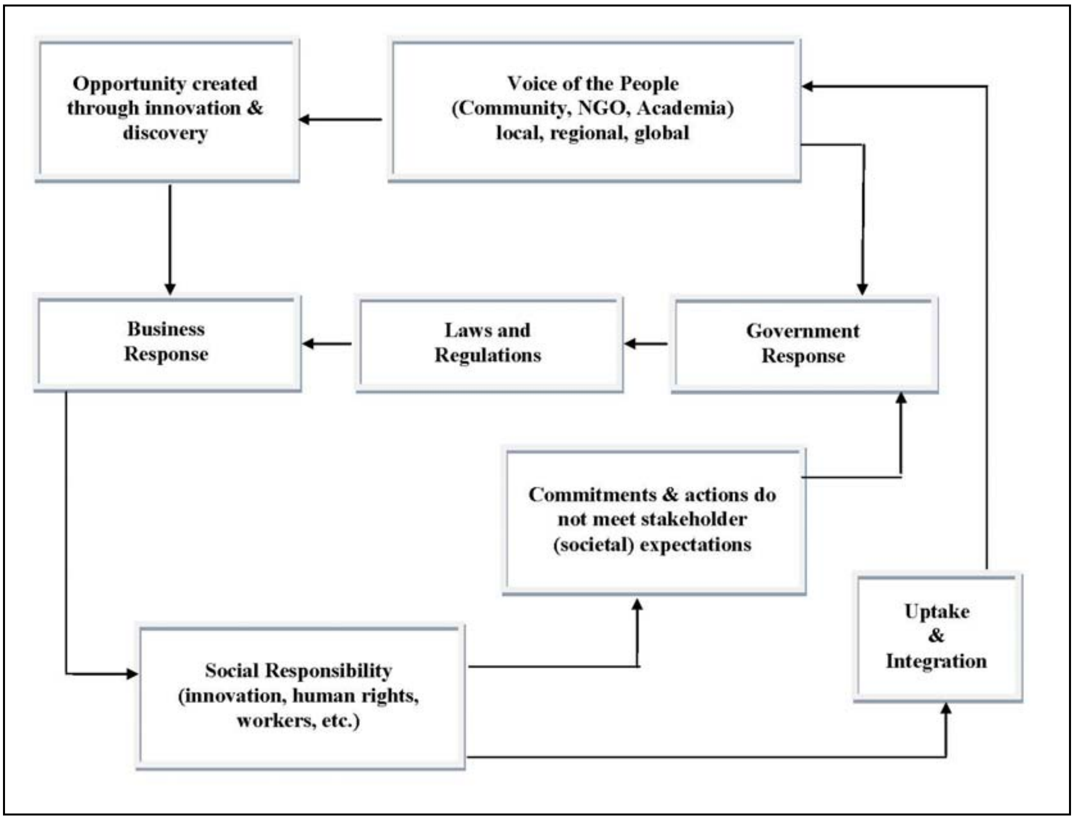


Figure 1 Sustainability Evolution

© ASCE 2014

Ethical Behavior as a Foundation for Business Sustainability

As society increasingly becomes aware of the consequences (e.g. ongoing exploitation of people and the environment) of unsustainable behavior, the resulting changes in attitudes are creating a shift in the ethical foundation of our culture. Even still, some believe *"our failure to address ethical issues when thinking about sustainability sciences has created serious problems for sustainability."* (Nelson and Vucetich, 2012)

Businesses' role, and more specifically, the role of the consulting engineers/scientists in restoring and maintaining a sustainable balance between societal needs, societal attitudes, and the environment is founded on a number of supporting pillars. Ethics is one of those supporting pillars. Ethics is defined as the *"moral principles that govern a person's or a group's behavior."* (OED Online) The definition of business ethics is the *"rules, principles, and standards for deciding what is morally right or wrong when doing business."* (Cambridge Dictionaries Online) Then there are those "*guiding principles designed to help professionals conduct business honestly and with integrity."* (Investopedia) defined as a "Code of Ethics." All founded in moral principles, there has been an evolution in some countries from a set of acknowledged moral principles to legal requirements for an actionable written ethical code for doing business. (e.g. in the United States one of the outcomes from Sarbanes Oxley[1] was the requirement for companies under the Securities and Exchange Commission (SEC) oversight to publish a code of business ethics or in the absence of a code of business ethics, the company must explain why they do not have one (SEC - 17 CFR Parts 228, 229, and 249).

It appears the challenge is that business has been slow to react on its own – acting when forced by regulation. While we may have a global economy, we do not all share the same culture. In business, these cultural differences bring differing ideas and ethical attitudes that can create the ethical dilemmas as businesses seek the license to operate globally. For example, the very concept of human worth is at play as evidenced by Table 1, which illustrates differences in fatality rates from various parts of the world, and begs the question: *"Why are some countries much higher than others...?"*

---

[1] Sarbanes-Oxley Act of 2002: On July 30, 2002, President Bush signed into law the Sarbanes-Oxley Act of 2002, The Act mandated a number of reforms to enhance corporate responsibility, enhance financial disclosures and combat corporate and accounting fraud, and created the "Public Company Accounting Oversight Board," also known as the PCAOB, to oversee the activities of the auditing profession.

© ASCE 2014

Country/Region	Occupational Fatality Rate per 100K Workers
Established World Economies (includes: United States, Canada, United Kingdom, Western Europe, Japan…)	5.3
India	11.0
Former Socialist Economies of Europe	11.1
China	11.1
Latin America and the Caribbean	13.5
World Average	14.0
Sub-Saharan Africa	21.0
Middle Eastern Crescent	22.5
Other Asia & Islands	23.1

Table 1 – Fatal Occupational Injuries across the World (adapted from the 1999 paper by J. Takala, published in Epidemiology).

One perception taken from the statistics provided by Takala (1999) is that life is not valued the same in all parts of the world and that in some regions there exists higher tolerances for worker exploitation. What is acceptable ethical business conduct is still open to interpretation – business drivers remain vested in a business case focused on stakeholder returns. As a company grows and extends its reach globally so must the ethical culture. Ethical dilemmas for business can occur when individuals make choices while representing the company that lead to results that are not consistent with:

- Societal/cultural accepted behavior outcomes;
- Stakeholder expectations; and
- Professional or company ethical codes.

In a global economy, whose operating capital is embedded/sourced in multiple cultures where varying moral compasses are at play, businesses are at an increased risk when it comes to ethical behavior – ethics can no longer be perceptional. It is with this view that companies are adopting and committing to international frameworks (e.g. UN Global Compact[2], Ceres[3], etc.) as the measure of the company's

[2] The Global Compact asks companies to embrace universal principles and to partner with the United Nations. It has grown to become a critical platform for the UN to engage effectively with enlightened global business < http://www.unglobalcompact.org/> June, 2014

© ASCE 2014

moral compass. The outgrowth is that a company's code of ethics provides a framework for conducting business and the expectation is for its employees to embrace the code of ethics and live it out daily. It is especially useful when problem solving as it ensures consistent behavior. Implicit in a company's code of business conduct is the embedding and growth of a shared business culture. The result of conducting business globally under a common code of ethics is demonstrated and made transparent through a company's Corporate Social Responsibility (CSR) Reporting. Increasingly, an outcome of CSR reporting is the establishment of a reputation for doing business in a socially responsible manner, which then translates to a Social License to Operate (SLO) locally and regionally on projects and globally as a company. Figure 2 provides the authors' view on the relationship between ethics, CSR, SLO, and business sustainability.

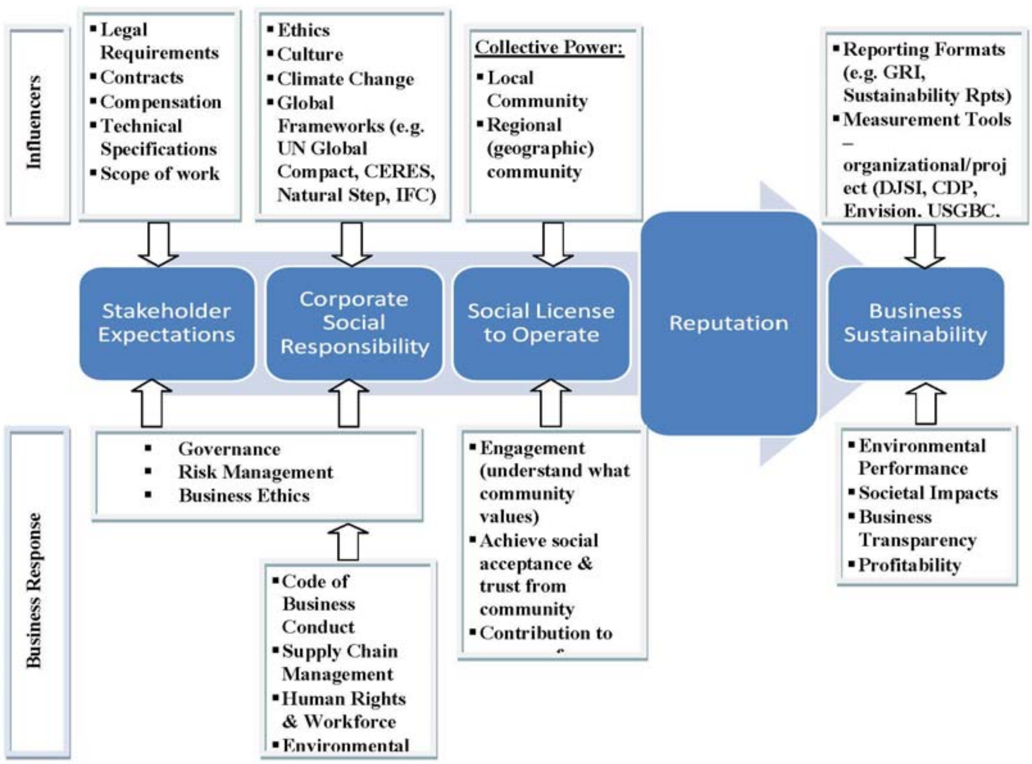


Figure 2 – Relationship between Ethics and Business Sustainability

---

[3] Ceres is a non-profit organization advocating for sustainability leadership. Ceres is a network of investors, companies and public interest groups acting to accelerate and expand the adoption of sustainable business practices and solutions to build a healthy global economy. < http://www.ceres.org/> June, 2014

© ASCE 2014

In Figure 2, we are acknowledging the relationship between one's SLO and the ethical choices made within the organization extending from the top to all levels of the organization. There are no doubt other influencers of a company's overall sustainability, but we believe the ethical framework in place dictates a company's social responsibility and ultimately how a company is publically perceived. It is this public perception that feeds its reputation, which in turn leads to its SLO and as long as a company maintains its SLO that business will be sustainable.

There is also an element of time, where a reputation needs to be developed. A SLO cannot be achieved overnight, it evolves, it comes from embedding oneself into the community and becoming part of the community, learning, listening and ultimately understanding what the community values as important. Because the SLO is typically community-driven, the SLO is earned locally, and depending on the size of the project/effort may extend regionally and globally. Indeed acting ethically and having in place the appropriate ethical expectations sets the tone and foundation for framing any CSR effort, which in turn translates into an organization's SLO.

In the absence of a single ethical framework, consistency in behaviors cannot be expected within a company/organization and the individuals will act in accordance with their own moral conscience. Likewise, individuals can choose to breach the ethical code deliberately. In either of these instances, the results can be disastrous for the company, placing at risk the company's reputation and SLO. Unfortunately, when individuals act independently their actions can have significant impacts on many. *"In the 1980's there was the Drexel Burnham Lambert and the savings and loans scandals. At the turn of the century, we saw Enron, WorldCom, Adelphi, and Tyco, to mention just a few. Most recently we witnessed the probably most systemic and widespread series of scandals of them all – the global financial meltdown of the past half-decade* (Bonime-Blanc, 2014)*."*

These are examples where the relationship between ethical behavior and personal and business sustainability made the headlines. Sustainability in the sense that many individuals woke up one morning to find their personal sustainability compromised by no action of their own, other than placing trust in the leadership of a large company. The actions of a few determinately affected the business's reputation and the business's SLO by severely damaging the credibility of the company. The opportunity in this is to understand, recognize and accept the ethical linkages between code of conduct, acting in accordance with that code and the sustainability of the business. Companies are internally having to determine what "not at any cost" looks like and must communicate and enforce their code. Otherwise, what value is the code?

© ASCE 2014

The consequences of not acting ethically carry unintended consequences for all. Such as the increased oversight and regulation of publicly traded companies by the SEC in the United States stemming from the Sarbanes Oxley Act of 2002 (SEC - 17 CFR Parts 228, 229, and 249).

Ethics in Engineering

Engineers have been graduating from universities around the globe long before sustainability was considered fashionable or even good business. In Canada, the Association of Consulting Engineering Companies (ACEC) has represented Canadian consulting engineering companies since it was created in 1925. In the United States, engineering companies are represented by the American Council of Engineering Companies (also the ACEC) which was founded in 1909.

In turn, both the Canadian and US ACEC's are members of the International Federation for Consulting Engineers (FIDIC). This global organization was founded in France in 1913 and represents the business and commercial interests of consulting engineering companies around the world. FIDIC is comprised of over 80 national associations, and its member organizations endorse the federation's statutes, comply with its Code of Ethics, and advocate the selection of engineering firms based on quality, as opposed to lowest price.

The International Federation of Consulting Engineers recognises that the work of the consulting engineering industry is critical to the achievement of sustainable development of society and the environment. To be fully effective not only must engineers constantly improve their knowledge and skills, but also society must respect the integrity and trust the judgement of members of the profession and remunerate them fairly (fidic.org,June, 2014)*."*

Member associations of FIDIC are required to subscribe to the following six (6) principles, which are viewed as fundamental to the behavior of their members if society is to have that necessary confidence in its advisors:

1) Responsibility to society and the consulting industry;
2) Competence;
3) Integrity;
4) Impartiality;
5) Fairness to Others;
6) Corruption.

© ASCE 2014

These fundamental behaviours are relatively self-explanatory and arguably the common cornerstones of any Code of Ethics. In addition, individual associations such as the Professional Engineers of Ontario (PEO) are guided by the Professional Engineers Act (R.S.O. 1990, CHAPTER P.28) and Section 77 of Regulation 941, which states that:

"it is the duty of a practitioner to the public, to the practitioner's employer, to the practitioner's clients, to other licensed engineers of the practitioner's profession, and to the practitioner to act at all times with,

- *i. fairness and loyalty to the practitioner's associates, employers, clients, subordinates and employees;*
- *ii. fidelity to public needs;*
- *iii. devotion to high ideals of personal honour and professional integrity;*
- *iv. knowledge of developments in the area of professional engineering relevant to any services that are undertaken; and*
- *v. competence in the performance of any professional engineering services that are undertaken.*

Through the Code of Ethics, professional engineers have a clearly defined duty to society, which is to regard the duty to public welfare as paramount, above their duties to clients or employers. Their duty to employers involves acting as faithful agents or trustees, regarding client information as confidential and avoiding or disclosing conflicts of interest. Their duty to clients means that professional engineers have to disclose immediately any direct or indirect interest that might prejudice (or appear to prejudice) their professional judgment." (Professional Engineers Act, Ontario Canada, 1990)

The province of Quebec has the Engineers Act (Chapter I-9, s.7) which outlines similar requirements.

It is when individuals choose to operate outside of their professional and company code of ethics, and are not identified in time, that huge losses (financial, reputational) occur, and some of these individuals and companies can never recover. In failing to adhere to a corporate or ethical code, they have lost the SLO, which can have a direct impact on the sustainability of their business.

In a perfect and sustainable world, engineers would follow the Code of Ethics of their association and achieve their primary mission, which is "*regard the duty to public welfare as paramount"* (Professional Engineers Act, Ontario Canada, 1990).

© ASCE 2014

Yet, in spite of local, national and even international Codes of Ethics for the engineering profession, we still see examples of the consequences of failure to follow simple ethical requirements. The engineering profession is not alone, but the examples are evident and the consequences (intended or unintended) are severe.

Recently and specific to the consulting engineering sector, the Charbonneau inquiry in Quebec has resulted in the discovery that *"a number of major engineering firms participated in a collusion scheme to raise the price of construction projects in Quebec. Even large publicly traded engineering firms were complicit in the cartel-like practices previously ascribed to lower-level construction companies in that province."* (Banerjee, 2015)

The impact of the misconduct was quantified by Daniel Lebel, Eng., FEC, PMP, President of the Order des ingenieurs du Quebec (OIQ) in a speech he delivered in November, 2013:

"Imagine if we were able to reduce the percentage of impact that misconduct in the public contract award and management process has caused by just one point, from 25% to 24%. That would bring back, in the most conservative way, 175 million dollars per year into the government's coffers. 1%. Think about it." (Lebel, 2013)

The financial impact is only one metric of the crisis. Reputation has also been significantly affected as the scale of the revelations revealed at the Charbonneau inquiry has greatly harmed the public's trust in the profession. An IPSOS survey conducted for the OIQ in 2013 confirmed that only 51% of Quebecers now have confidence in engineers, compared to 74% in the mid-2000's (Lebel, 2013).

Additional challenges include:

- effective disciplinary controls and actions to be applied to the offending engineers;
- risk of losing competitive edge to several countries and provinces that are just as able to compete in attracting investments and industry;
- Ability to rectify the major lack of maintenance affecting Quebec's strategic infrastructures of which the Champlain Bridge is a prime example of both lack of maintenance and a lack of long-term (sustainable) vision.
- Loss of approximately 20% of staff from the organizations who comprise the Association of Consulting Engineers of Quebec (AICQ, 2014); and
- Increased competition among those engineering firms struggling to hold on to key staff and survive financially.

© ASCE 2014

The AICQ is intent on introducing a program that would audit the business practices of consulting engineering firms, which has never before been completed. This sounds very similar to the Sarbanes Oxley Act in the United States that resulted from the financial scandals in the early 2000's.

Maintaining an SLO

For any engineering company, a SLO is important because an individual or perhaps an entire company is only as good as their reputation.

Over a decade ago, FIDIC produced a guidance document entitled *"Sustainability Management"* and more specifically *"Project Sustainability Management"* (FIDIC, 2004a) These PSM guidelines were intended to enable project owners and consulting engineers to devise and customize a wide range of identified key performance indicators to meet stakeholder concerns and issues, while demonstrating a link to sustainable development (FIDIC, 2004b). There were three (3) Project Stages envisioned:

Stage one – Establish project-specific goals and indicators for sustainable development;
Stage two – Adjust project goals and indicators to local conditions; and
Stage three – Test and refine project goals and indicators.

Throughout implementation of all three stages, stakeholder engagement was viewed as mandatory. The PSM Guidelines also provided numerous Core Project Indicators in the three (3) typically known sustainability pillars, Social, Environment and Economic, which were derived from the United Nations Commission on Sustainable Development (UN CSD) indicators, which refer to Agenda 21 issues. Social themes include, poverty, health, human rights, education, literacy, housing, culture and integrity (bribery and corruption) (FIDIC, 2004c).

The PSM Guidelines and the approach to sustainability have evolved in the last decade, perhaps in the same manner that sustainability has evolved. The framework for including stakeholders and ensuring stakeholder engagement was established long ago, long before FIDIC, but was certainly re-enforced by FIDIC and could arguably be the roots of the newly coined phrase *"social license to operate"* which is attributed to Canadian mining executive Jim Cooney in the late 1990's (Mining facts.org, June 2014).

The SLO began as a metaphor for the ability of communities to stop mining projects. Today the concept has spread to other industries and it is becoming a general

© ASCE 2014

management approach to winning the acceptance, approval and support of stakeholders and communities (ACCSR).

Perhaps the undoing of a number of major engineering firms and their collusion scheme in Quebec can be attributed to failure to engage stakeholders and the inability to obtain a SLO.

Acceptance, approval and support does not come easily especially on contentious development initiatives such as a new mine site, new pipeline, nuclear power plant, dam, road, etc. Failure to follow your own associations or organizations Code of Ethics does not lend itself to a very sustainable business and quite quickly can result in the loss of trust, a key component in obtaining and maintaining an SLO. Examples of the consequences of loss of trust and the intended and unintended consequences exist all around us in the business world.

The SLO is described as a barometer or measurement of the socio-political risk of a project and these risks first appear during stakeholder engagement. Unfortunately, a search for the words "Social License" on both the US and Canadian ACEC websites and the FIDIC website produced no results. We still have progress to make and the evolution of sustainability continues.

Conclusion

When people operate outside their code of ethics, companies may suffer huge losses (financial, reputational), which will impact their SLO to operate and hence ultimately the sustainability of their business. Although only one part of business paradigm in the 21st century, attention to Corporate Ethics needs to be a core component of any boardroom agenda. Good corporate and socially responsible organizations recognize business ethics, sustainability and social responsibility as essential components of running a successful business as well as essential for long-term (sustainable) success. It is the ethical attitudes/foundations a society places on continuing acceptance of exploitation of people and the environment that will influence the pace at which technology can be developed and deployed to restore the balance between society and the environment that will in turn *"provide the capacity and opportunity to maintain and improve quality of life indefinitely…"*(ASCE, 2009). Engineers have a key role to play in the evolution of sustainability in today's world and should take this responsibility seriously. Sustainability is collectively a societal journey and a continuing evolution, the pace of which is guided by the ethical attitudes of an individual and society. Society will ultimately decide the SLO or sustainability of an organization and success will hinge on transparency and trust.

© ASCE 2014

REFERENCES:

ACCSR Services. "Social License to Operate" <http://www.accsr.com.au/pdf/ACCSR_Social_License1b.pdf> June, 2014.

American Society of Civil Engineers (ASCE) – definition of sustainability American Society of Civil Engineers (ASCE) Sustainable Development Committee. *Approved by the ASCE Board Direction,* October 28, 2009.

Association of Consulting Engineers of Quebec (March 1, 2014). <http://www.canadianconsultingengineer.com/news/conversations-collateral-damage-an-interview-with-johanne-desrochers-aicq/1002995481/> June, 2014.

Banerjee, S. (January 24, 2013). "*Quebec Corruption Inquiry: Major Engineering Firms, Including SNC-Lavalin, were in on Quebec Collusion, Inquiry Hears*" Published by The Canadian Press, <http://www.thestar.com/news/canada/2013/01/24/quebec_corruption_inquiry_major_engineering_firms_including_snclavalin_were_in_on_quebec_collusion_inquiry_hears.html> June, 2014.

Beckhard and Harris. (1987). *"Change Model"* <http://www.wheel.ie/sites/default/files/Beckhard-Harris%20Change%Model-DVF.pdf> (June, 2014).

Bonime-Blanc, A. (2014). The Global Ethicist – The Biggest Risks Nobody Talks About. Published on *Ethical Corporation* (http://www.ethicalcorp.com) <http://www.ethicalcorp.com/print/37114> June, 2014.

Business ethics. *Cambridge Dictionaries Online* - Cambridge Business English Dictionary. Cambridge University Press < http://dictionary.cambridge.org/us/dictionary/business-english/business-ethics> June, 2014.

Ethics. *Oxford's English Dictionary (OED) Online.* Oxford University Press <http://www.oxforddictionaries.com/us/definition/american_english/ethics> June, 2014.

Hardin, G. (2008). "Tragedy of the Commons." *The Concise Encyclopedia of Economics. 2008. Library of Economics and Liberty*. <http://www.econlib.org/library/Enc/TragedyoftheCommons.html>. June, 2014.

International Federation of Consulting Engineers (FIDIC). (2004a). *FIDIC Project Sustainability Management Guidelines*.

International Federation of Consulting Engineers (FIDIC). (2004b). Foreword – *FIDIC Project Sustainability Management Guidelines*, 2004

International Federation of Consulting Engineers (FIDIC). (2004c) – *FIDIC Project Sustainability Management Guidelines*, page 21-22.

© ASCE 2014

International Federation of Consulting Engineers (FIDIC). FIDIC Code of Ethics. <http://fidic.org/node/743> June, 2014.

Investopedia. Definition "Code of Ethics" <http://www.investopedia.com/terms/c/code-of-ethics.asp> June, 2014.

Lebel, D, Eng., FEC, PMP, President of the Ordre des ingenieurs du Quebec. (November 28, 2013). Notes for a speech <http://www.oiq.qc.ca/Documents/DCAP/allocution/AMBAQ_speech_president_2013.pdf> June, 2014

Mining Fact.org. What is a Social License to Operate. < http://www.miningfacts.org/Communities/What-is-the-social-licence-to-operate/?terms=Jim Cooney> June, 2014.

Nelson, M. P. & Vucetich, J. A. (2012) Sustainability Science: Ethical Foundations and Emerging Challenges. *Nature Education Knowledge* 3(10):12 http://www.nature.com/scitable/knowledge/library/sustainability-science-ethical-foundations-and-emerging-challenges-24319566 June, 2014.

Professional Engineers Act (Ontario, Canada) (1990): R.S.O. 1990, CHAPTER P.28 < http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_90p28_e.htm> June, 2014.

Professional Engineers Act (Ontario, Canada) (1990): R.R.O. 1990, Regulation 941 Section 77 Code of Ethics < http://www.e-laws.gov.on.ca/html/regs/english/elaws_regs_900941_e.htm> June 2014.

Securities and Exchange Commission (SEC). 17CFR Parts 228,229, and 249 Disclosure *Required by Sections 406 and 407 of Sarbanes Oxley Act of 2002*; <http://www.sec.gov/about/laws/soa2002.pdf.> June, 2014

Takala, J. (1999). Global Estimates of Fatal Occupational Accidents, *Epidemiology*, 10, 640-646. <http://www.who.int/quantifying_ehimpacts/methods/en/takala.pdf> June, 2014.

© ASCE 2014

Building Crossrail – A holistic approach to Sustainability

Michael de Silva[1] & Robert Paris[2]

[1] BSc, Ph.D., FCIWEM, MIEEM C.WEM, CSci. Bechtel Ltd, Crossrail Sustainability Manager, Crossrail Ltd, 25 Canada Square, Canary Wharf, London, E14 5LQ, UK
[2] BSc, MSc, MCIWEM, MIES. Head of Sustainability & Consents, Crossrail Ltd, Crossrail, 25 Canada Square, Canary Wharf, London, E14 5LQ, UK

ABSTRACT

At Crossrail, we are passionate, not just about building a new railway but ensuring it is delivered in a way that provides a lasting economic, environmental and social sustainability legacy. We have enshrined this in our strategy and governance processes and our contractors have joined us on this journey.

This paper provides a comprehensive yet concise account of how Crossrail has organized itself to deliver a sustainable outcome as well as detailing a structure for successful outcomes.

This paper covers 4 main themes:

- Planning for delivering sustainability on a major infrastructure project
- Creating a Sustainability Governance Structure to manage sustainability performance
- How the use of sustainability assessment methodologies have helped outcomes
- Encouraging innovation to deliver better sustainability outcomes

This paper will be of particular interest to client organizations responsible for national infrastructure, but also provides valuable information for designers and construction professionals

WHAT IS CROSSRAIL?

At £15Bn, Crossrail is the largest infrastructure project in Europe and forms a major part of the Mayor of London's Transport Strategy. Crossrail will connect 37 stations, including Heathrow airport and Maidenhead in the west with Canary Wharf, Abbey Wood and Shenfield in the east. Using the Crossrail service will make travelling in the region easier and quicker, and help to reduce crowding on London's transport network. Crossrail, as a public transport project, delivers sustainable outcomes by relieving overcrowding on existing underground and train services adding 10 per cent extra rail capacity for London and decreasing journey times across London.

© ASCE 2014

The new sub-surface stations will be on a scale larger than that of the Jubilee Line Extension, London, which opened in 1999, connected by new tunnels measuring 21km in length. Around 200 million passengers will travel on Crossrail each year. The project will deliver substantial economic benefits to London and across the UK and brings an additional 1.5 million people within 45 minutes commuting distance of London's key business districts.

Crossrail has let some of the largest value contracts in recent UK construction history, providing a much needed boost to UK industry and creating major employment opportunities. During the construction phase alone, Crossrail will generate thousands of jobs peaking at 55,000. It will also require the services of regionally based manufacturers and other suppliers. The estimated benefit of Crossrail to the UK economy is at least £42 billion over a 60 year period.

Furthermore, the manner in which Crossrail is delivered and the resultant legacy of skills, learning, contribution to UK cultural heritage and good stakeholder relations is vital not only to the delivery of Crossrail but also to the support by statutory authorities and civil society for the delivery of future major projects in London and the UK. In order to ensure that sustainability was built in to business planning, Crossrail produced a Sustainability Strategy. The strategy has been developed into key sustainability themes that are material to the delivery of the project and then identifies key performance indicators that are used to track performance.

The holistic approach is such that the project takes a balanced view on environmental, social and economic performance. Ownership of different aspects of this performance lies across several directorates across the organization, but is coordinated at a working level by a Sustainability Co-ordination group, and reports regularly to a Sustainability Committee, represented by the senior management team. A dashboard approach is used to demonstrate performance and an accountability structure is linked to a reward system for good performance.

Whereas many projects have focused on the environmental aspects of sustainability, Crossrail has been particularly successful at addressing issues of supply chain and SME (Small & Medium Enterprise) engagement, supply chain risk management, local employment, skills and training and ensuring that opportunities are not confined to the prosperous south east of England.

The paper will develop these themes and explain how this is being implemented

BUILDING SUSTAINABILITY INTO CROSSRAIL AND HOW WE DO BUSINESS

In order to ensure that sustainability was built in to business planning, Crossrail produced a Sustainability Strategy. The Strategy set out a definition of sustainability for Crossrail that is inclusive and far-reaching. Seven sustainability themes have

© ASCE 2014

been adopted reflecting Transport for London's (TfL) sustainability framework, UK Government priority areas and Department for Transport policy. (See diagram below). The principle of 'good governance' is to be applied across all seven themes. The principle of 'using sound science' underpins all aspects of the design and construction.

Six of the Crossrail sustainability themes align closely with those for TfL. The seventh, sustainable consumption and production, reflects that Crossrail is a massive infrastructure project and the use and final disposal of materials is particularly important.

The Crossrail approach to delivering against these sustainability themes has been to establish 15 Key Sustainability Initiatives (KSI) that are designed to deliver the requirements of each sustainability theme. Fig 1 completes the picture, with the UK sustainable development goals and the Crossrail sustainability themes realised through the KSIs. In addition, there are three cross-cutting initiatives the undertaking of which is relevant to the delivery of each of the KSIs.

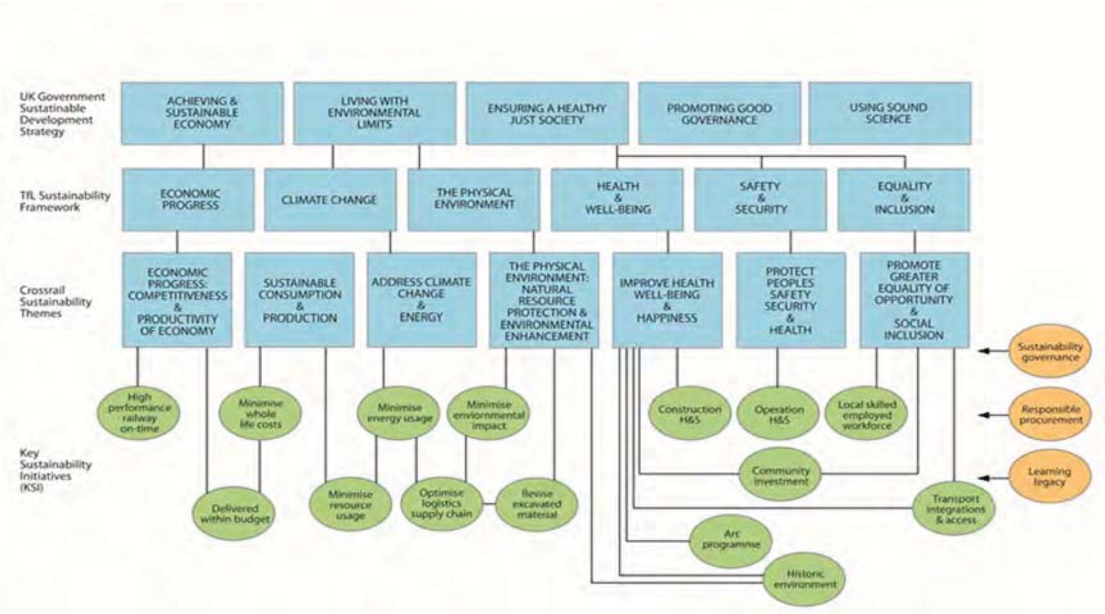


Fig 1. Crossrail's Sustainability Themes and Key Sustainability Initiatives as defined in its Strategy

CREATING A SUSTAINABILITY GOVERNANCE STRUCTURE MANAGING SUSTAINABILITY PERFORMANCE

Responsibility for the realisation of each of the KSIs has been assigned to senior management under the overall direction of the Chief Executive. Each Crossrail

© ASCE 2014

directorate is then either given or required to identify specific sustainability objectives and targets as part of the annual business plan cascading these into individual objectives as required. Each year Corporate KPIs are established against which top level management and partner organisations are financially incentivised, of which a large proportion are set to attain a high level of sustainability performance.

Key Performance Indicators (KPIs) are developed for each KSI reported in three dashboards, one each for social, environmental and economic sustainability and monitored on a quarterly basis by the Sustainability Committee. Dashboards to be included in final paper.

The Committee provides overall sustainability governance, promotes achievement of the sustainability objectives, and supports cross project sustainability initiatives and those responsible for carrying them out, providing oversight, guidance and escalation routes if required. Every year it reviews the overall sustainability performance to-date and signs off the publication of the Annual Crossrail Sustainability Report, accessible via the Crossrail website http://www.crossrail.co.uk.

This governance structure and commitment to voluntary annual reporting is quite unique to a temporary organisation.

A supplier performance framework is also being implemented (Fig 2). This is a twice yearly performance assessment of contractors against contract requirements and assessing beyond compliance performance as Added Value and World Class (Fig 3). This is reported to the Crossrail Executive and back to contractors to compare their performance.

Fig 2. Supplier Assurance Framework coverage

© ASCE 2014

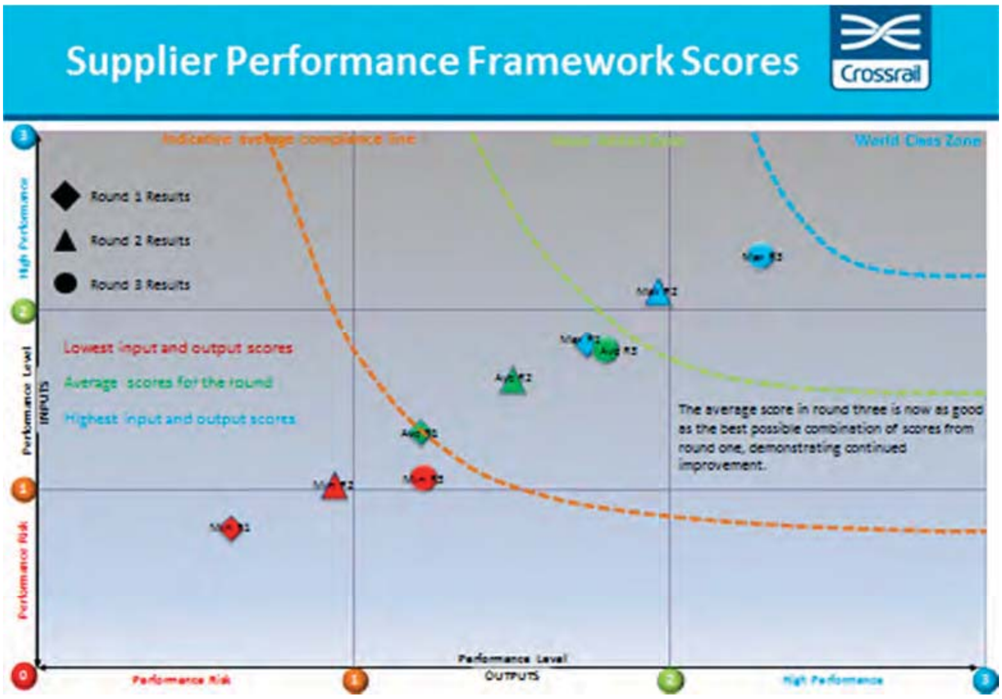


Fig 3. Supplier Performance Framework Scores

OUR SUSTAINABILITY POLICIES AND HOW THEY DRIVE PROCUREMENT

Crossrail's commitment to sustainability is further underpinned by a number of key policies: Environment, Carbon Footprint, Equality & Dignity, Health & Safety, Inclusivity and Whole Life Costing.

Crossrail's Procurement Strategy embodies the seven themes of Responsible Procurement[1] and these are all articulated within the contracts with our principal contractors who report on performance on a 4-weekly or quarterly basis.

Sustainability requirements have been written into all Crossrail contracts in line with the Themes and KSIs found within the Sustainability Strategy. Examples of the Crossrail policy requirements that have been cascaded to our Contractors within the works information that forms part of the contractual documentation are included in the list below. Core elements of the works information are taken from the Crossrail Environmental Minimum Requirements (EMR) . The EMR are standards and procedures that have been agreed with local authorities and statutory agencies in order to control and manage environmental impacts. This includes the Construction Code, which explains how contractors work will be controlled. The Crossrail

[1] Encouraging a diverse base of suppliers , promoting fair employment practices, promoting workforce welfare, addressing strategic labour needs and enabling training, community benefits, ethical sourcing practices; and promoting greater environmental sustainability.

© ASCE 2014

Construction Code represents best practice environmental management and is widely considered to have "raised the bar" on construction performance requirements in the UK.

Key elements of delivery are:

- Environmental requirements are contained within the works information and include a number of minimum performance levels in addition to specific targets. These requirements are extensive and cover management of carbon & energy, noise & vibration, dust & air quality, pollution control, water & material resources, archaeology & historic environment
- All contracts use BREEAM (stations) or CEEQUAL (tunnel, portals and shafts) as an environmental assessment methodology and benchmarking tool
- All personnel employed on the project are to be paid the London Living Wage.
- Contractors must use of CompeteFor and Diversity Works for London to allow local business to compete for work and achieve good diversity practice
- All contractors are required to produce Community Investment Plans. This requirement is aimed at encouraging contractors to deliver time and money to good causes locally – putting something back into the communities where Crossrail's construction works are causing the most disruption,
- All Contractors must register with the Considerate Constructors Scheme. The Crossrail average is 42.5 (national average of 34.64).
- Crossrail has set a target of 400 new apprenticeships working on Crossrail for at least 16 weeks.
- Crossrail has established a free job brokerage service. Jobcentre Plus is working with our Contractors and with a network of local outreach agencies to identify and advertise job vacancies and help equip local people to compete for these opportunities.
- Project bank accounts (PBA) – All tier 1 contractors are required to establish PBAs to pay sub-contractors. Crossrail can monitor the balances to ensure they are maintained at a low level indicating that suppliers are being paid promptly (within 30 days). This is vital to ensure that money is flowing to vulnerable SMEs
- Risk mitigation – supply chain exposure is continually monitored to ensure that risk is spread and that suppliers i) have capacity to supply to Crossrail and ii) are not overly dependent on Crossrail as a sole or predominant customer.

CROSSRAIL WORKING GROUPS, FORA AND OTHER ENABLERS FOR INDUSTRY BEST PRACTICE

Crossrail recognises that contractual requirements alone are not going to deliver world-class performance. The importance of having a common vision, collaborative working environment and performance incentives is also vital in ensuring successful outcomes. Collaborative working and information sharing in order to accelerate

© ASCE 2014

performance improvement has been promoted through a number of fora. For example Crossrail runs:

- A regular Contractor Environmental Managers forum and collaboration website to share best practice and lessons learned across the programme of works.
- A regular Ethical Supply Chains in Construction working group with procurement specialists from our tier 1 contractors who are working collaboratively to mitigate risks in the supply chain. The work of this group has received external plaudits for the work that it is undertaking.
- A project carbon working group bringing together corporate sustainability managers from across our tier 1 contractors, to work collaboratively and mobilise their combined procurement power to deliver a lower carbon solution for Crossrail, and develop industry knowledge for future projects. A focus of this group is to demonstrate tangible links between lower carbon and lower cost.
- An innovation programme, unique to a temporary organisaiton. This programme legitimises our workforce to promote ideas that can improve the efficiency of construction. The Innovation Forum evaluates ideas in the form of a competition and provides funding for implementation. Ideas can be of a scale for implementation on Crossrail or of a more experimental nature to provide confidence for future projects.

  An analysis of the 400+ submissions to the innovate portal have shown that many are sustainability related. As such, the huge power of implementing a project innovation programme to harness sustainable project benefits is immense. We are also starting to see emerging correlations between the level of innovation within our contractors (and their supply chains) and their overall performance in the supplier performance framework. Furthermore, there is emerging and powerful data linking organisations that innovate with greater profitability.

  The organisational structure of the platform ensures that contributing contractors each benefit from the programme with very little investment, and the project can act as an accelerator to bring solutions to market.

MEASURING PERFORMANCE ON CROSSRAIL: TOOLS AND TARGETS

Construction Energy

Discussion within the industry and notably Constructing Excellence[2] (CE) highlights that there is little benchmark data for the heavy construction activities being

[2] Constructing Excellence is the single organisation, in the UK, charged with driving the change agenda in construction. It exists to improve industry performance in order to produce a better built environment. It is a cross-sector, cross-supply chain, member led organisation operating for the good of industry and its stakeholders.

© ASCE 2014

undertaken on Crossrail. We are thus pioneering an approach to understand the entire carbon footprint of Crossrail over its operational life, but also focussing at the present time on construction energy. This has led to carbon reductions of up to 20 per cent, with an average of over 8 per cent across the programme. Crossrail data will be made available to the industry through CE. We have also developed a number of spreadsheet based macro calculations that can be "plugged in" to our construction carbon footprint module so that the benefits of a particular techology or initiative in reducing energy and carbon can be immediately calculated and the impact on the out-turn carbon seen.

BREEAM/CEEQUAL

Crossrail uses two environmental sustainability evaluation schemes, BREEAM & CEEQUAL, a description of which follows.

BREEAM (Building Research Establishment Environmental Assessment Methodology) is an environmental assessment method and rating system for buildings, with 250,000 buildings with certified BREEAM assessment ratings and over a million registered for assessment since it was first launched in 1990. It is similar to LEED, ESTIDAMA, and GSAS. Crossrail is the first project to utilise BREEAM for the assessment of an underground station. Through collaboration with the Building Research Establishment , Crossrail has developed criteria that are suitable for this type of building. This is an industry leading initiative allowing future benchmarking for underground stations.

CEEQUAL (Civil Engineering Environmental Quality) Award Scheme was launched in 2003 and is a similar scheme for civil projects and is being used to evaluate Crossrail's tunnel, portal & shaft structures. A recent equivalent in the USA is ENVISION which was developed after consulation with CEEQUAL Ltd.

The use of these methodologies has provided a rigour to the evolving design process and has aided the focus on poorly performing areas such that improvements can be made. Contractor performance can also be measured through the use of CEEQUAL which has a heavy points weighting on the physical contruction process and environmental management thereof.

The transitioning of both the BREEAM & CEEQUAL processes to our contractors has allowed them to seek areas for improvement and performance is rewarded through the Supplier Performance Framework.

Excavated Material & Construction Waste

Crossrail has set targets of 95 per cent and 90 per cent respectively for the diversion of these materials from landfill to beneficial use. The project is currently in excess of both of these targets, with nearly 100 per cent construction waste being diverted

© ASCE 2014

from landfill and 99 per cent of excavated material being beneficially used, a significant volume of which is being used for the Wallasea Island wild coast project.

Wallasea Island in the Thames Estuary will be transformed from levee-protected farmland into a thriving wetland, twice the size of the City of London and teeming with bird and marine life. The project, never before attempted on this scale in Europe, has been made possible through a partnership between the Royal Society for the Protection of Birds (RSPB). The loss of coastal habitat over the past four centuries has been dramatic. Without projects like Wallasea, rising sea levels are threatening to see another 1,000 hectares lost in the next decade. Wallasea will provide 670 hectares of habitat for wetland wildlife to thrive and the RSPB predicts a significant increase in the number of birds once the project is completed.

Diesel Emissions Control

Crossrail is committed to reduce emissions from non-road mobile machinery where reasonably practicable. The use of these cleaner engines will contribute towards improving air quality in London and particularly for Crossrail's local communities. Since 2010, we have been working with contractors to implement this requirement and to overcome concerns relating to equipment reliability, maintainability and adverse fuel consumption. By 2013/14, 73 per cent of all plant used on the project had been fitted out with diesel particle filters (dpf) or have been procured with Stage 3b engines. Trials have proven that it is not practical to fit emissions control to 19 per cent of plant at this time (equating to 92 per cent compliance). This programme has been instrumental in increasing the capacity and therefore availability of dpf fitted plant & equipment to the London & south east of England market.

THE IMPACT CROSSRAIL ON STIMULATING ECONOMIC GROWTH, JOBS, SKILLS AMND COMMUNITY BENEFITS

As the largest infrastructure project in Europe, Crossrail is creating jobs and stimulating growth in the UK. Data representing 1751 contracts from tier 1 to 3 indicates that 62 per cent of the project's supply chain spend is taking place outside of London and 58 per cent are SMEs. 97 per cent of Crossrail related contracts are being delivered by UK based companies.

This data has been used to map the geographic distribution of the supply chain (Fig 4), highlighting some of the specific opportunities being delivered around the UK. The project has so far supported the equivalent of 13,800 full time jobs right across the UK, with three out of five of these jobs outside of London.

Another key objective for Crossrail has been to ensure engagement with the supply chain, and importantly to try and create new opportunities for companies that may not otherwise have the opportunity to work on a programme such as Crossrail. Our

© ASCE 2014

use of CompeteFor, an online resource that flags up potential contracts to these companies, has proved a successful tool in promoting opportunities and bringing new suppliers to the table. Given the opportunity to perform, there is every chance that these companies can become more regular members of the supply chain to our tier 1 contractors. We will be doing more analysis on just how successful this has been next year.

Fig 4. *Geographic distribution of the Crossrail supply chain*

© ASCE 2014

London is an expensive city in which to live and work, and it is important that the more vulnerable members of our workforce are protected through payment of the London Living Wage[3]. A programme of audits is employed to ensure that this is being complied with, and we are not aware of any non-compliance in this area.

Community Investment Programme

We work in close proximity to our communities. A project such as Crossrail is built in the heart of the city and the impacts on local community can be significant. Furthermore, the duration of the works means that our contractors are very much part of the community for the duration of their tenure on the project. We therefore require them to put something back into the community and this takes the form of various initiatives. In some cases, this may be simply providing money for a community project, but more typically takes the form of donations of construction materials for community projects, or volunteer time to assist on projects. Crossrail Ltd also has its own Community Investment contributing to the programme focussing on a number fo schools in the area and linked in with the Young Crossrail initiative. Young Crossrail is our education programme for students. It targets both junior and senior school students with appropriate educationall materials. It has been set up in response to the increasing challenge in the UK of attracting people to the engineering & construction industry. A career in engineering can be exciting, varied and rewarding. Whilst our mission at Crossrail is to deliver a world-class railway for the 21st century, engineering also plays a key role in a broad range of industries outside the transport sector and this programme is designed to take this message out to local schools. We have a number of volunteers from the project that go out and work with the school, but resources are also available for the schools to work on their own.

REWARDING OUR CONTRACTORS

In 2013, a decision was made to reward our contactors for their sustainability endeavours. To this end, the Crossrail Annual Sustainability Awards were launched with entries invited in the three categories of economic, environmental and social sustainability. This is also very much linked to our learning legacy and the sharing of information across the industry.

---

[3] The London Living Wage is the hourly rate of pay that the Greater London Authority Economics calculate each year, taking into account the higher cost of living in the capital and the rate of inflation, which is needed to be paid to someone to allow them an acceptable standard of living above the poverty threshold. It is defined by GLA Economics as "a wage that achieves an adequate level of warmth and shelter, a healthy palatable diet, social integration and avoidance of chronic stress for earners and their dependents."

© ASCE 2014

We also recognised the importance of instigating behavioural change and initiated a campaign known as Green Line. Contractors are required to demonstrate above compliance performance across a number of environmental criteria to be awarded the green line. The line is a physical and visible symbol at the site entrance to signify a best practice site and promotes pride amongst the workforce. During the year, Green Line recognition was awarded to seven contractors and partner organisations. The above compliance requirements of recognition under the Green Line also feeds in to the supplier performance framework, thereby providing additional reward.

SUMMARY

In summary, it can be seen from the approach taken on Crossrail that an early and clear definition of sustainability with clear lines of ownership, responsibility and governance can be co-ordinated and managed across diverse interests to provide benefits that are balanced and address social environmental and economic needs. The outcomes from this are demonstrated through the results and confirm the success of this approach which we commend to other major projects.

On completion Crossrail will leave a tangible physical legacy but arguably the intangible legacy of a change in construction industry sustainability performance and the recognition that the benchmark for construction and major projects has been raised will be a greater achievement. Crossrail is paving the way for future projects and is proving that it can be affordable and, indeed, financially and economically beneficial to pursue sustainable outcomes, particularly when wider benefits to the national economy are taken into consideration: the contribution to the economy reaslised through improved accessibility and journey time being the more direct benefits, but wider benefits such as the opportunitity for employment, training and supply chain enhancement are derived through investment in sustainable infrastructure The authors would argue that this is a vital consideration in the calculation of benefits when undertaking evaluation of infrastructure projects, although we would accept that the industry would benefit from further tools to aid this evaluation.

© ASCE 2014

Impacts and Mitigation Strategies from Solar Array Systems within Colorado Department of Transportation's Highway Right of Way Areas

Arthur H. Hirsch

TerraLogic Sustainable Solutions, 5766 Flagstaff Road, Boulder, Colorado 80302; PH (303) 786-9111; email: AHirsch@TerraLogicss.com

ABSTRACT

Highway Right of Way (ROW) areas are becoming to be recognized as potential alternative energy resources to many state departments of transportation (DOTs). In an era of limited state DOT budgets, ROW areas can be a source of income and cost savings to DOTs for alternative energy development, especially in the area of solar energy. State DOTs and private Tollway Authorities have been leasing ROW areas to energy providers to offset carbon footprint emissions or obtain financial resource through long term lease agreements. Research was conducted to identify the potential risk-based impacts associated with the construction and operation of solar array systems within the Colorado Department of Transportation's highway right of ways that are associated with driver safety, environmental resources, and operation and maintenance activities. Literature searches, professional communications and computer modeling of glare impacts were performed at study site areas. The main potential impacts were associated with increasing snow drifting and deposition, glare, stormwater management, potential vehicle collisions with solar array structures, noxious weed introduction and altering mowing operations.

INTRODUCTION

The utilization of solar energy within highway Right of Ways (ROWs) has been increasing since 2008 when the first ROW-solar system was developed by the Oregon Department of Transportation. The State of Colorado has a very high rate of solar insolation that makes solar energy generation feasible. Effective utilization of unused ROW areas across Colorado has a potential to produce a significant amount of electricity from photo voltaic (PV) systems. The Colorado Department of Transportation's (CDOT) initiation to explore and evaluate the highway ROW for possible solar system installation is a proactive step towards alternative energy generation by Energy Developers or by CDOT.

CDOT has an estimated 55,500 Giga Watt Hour (GWh)/year of power generation capacity associated with solar energy development within their ROW area statewide as reported in the "Assessment of Colorado Department of Transportation Rest Areas for Sustainability Improvements and Highway Corridors and Facilities for Alternative Energy Use (CDOT Applied Research 2011). Based on the PV

© ASCE 2014

technologies; space availability; site characteristics; and solar array system design, orientation and energy capacity; solar array systems could effectively be installed in CDOT's property.

The highway ROW can be a valuable resource for alternative energy development to DOTs. ROWs provide several advantages to energy development such as electrical infrastructure corridors (power lines/utilities), limited security protection to solar array arrays, area maintenance, undisturbed land, and easy access. ROWs within high solar insolation areas provide an opportunity for CDOT to develop solar power systems across much of the State of Colorado.

TerraLogic Sustainable Solutions and Colorado State University at Pueblo (Research Team) combined efforts to assess the safety, environmental and operation and maintenance impacts associated with the placement of solar array systems within CDOT ROW.

PROJECT GOALS AND OBJECTIVES

The goal of this report is to identify specific safety, environmental and operational concerns and impacts associated with the potential development of solar array systems in CDOT ROWs. Risk factors are identified and mitigation strategies are conceptualized to eliminate or reduce potential impacts. This information will be important for CDOT representatives such as Project Managers, Right of Way Managers, Maintenance Managers and external Energy Developers to identify and manage risks associated with solar array system deployment.

This research provided guidance for CDOT Management, Project Engineers, Operation and Maintenance personnel and energy developers who are interested in installing and maintaining solar array systems in the CDOT ROW. The following are the main objectives of the Project:

- Develop a general model of a solar highway focusing on user safety and maintenance activities
- Study and analyze the impact of highway solar array systems on road maintenance, driver safety and environmental resources
- Identify and list the critical risk factors in solar array system deployment and develop risk reduction strategies
- Provide CDOT a guidance manual that will provide basic considerations and requirements to address CDOT environmental, safety and operation and maintenance expectations
- Identify design and safety guidance considerations pertaining to highway solar array design, installation, and operations and maintenance

© ASCE 2014

PROJECT APPROACH

The scopes of the project encompass five tasks and were carried out in coordination and communication with CDOT study manager, CDOT field coordinator, the maintenance and ROW representatives and members of the project study panel. The following is a list of the main tasks performed for the project:

- Literature Search and Assessment
- Study Framework Development
- Study Framework Execution and Evaluation
- Report Development and Presentation

Solar Array System Components. Solar array systems use solar cells that are made of layers of semiconducting materials. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. The following describes the basic solar array components (Tribal Energy and Environmental Information) that would be used in a highway ROW scenario (Figure 1).

The three main types of materials used for solar cells are:

- Silicon, which is used in various forms such as single-crystalline, multi-crystalline, and amorphous;
- Polycrystalline thin films, using copper indium, diselenide cadmium telluride, and thin-film silicon
- Single-crystalline thin film using gallium arsenide

Photovoltaic (PV) technologies include flat plate and concentrating systems. Flat plate systems use solar panels, designed to allow sunlight to strike the solar cells directly, without the benefit of any light-concentrating or focusing device. As the conversion efficiency of most solar cells increases with increasing intensity of incident light, a concentrating device such as a Fresnel lens can greatly increase the amount of electricity generated by the solar cells.

There is usually a security chain link fence that surrounds the solar array system in the Clear Zone Area (30 feet from the edge of pavement). Chain link fencing provides some security against vandalism and theft. Some systems used razor wire and/or security cameras.

© ASCE 2014

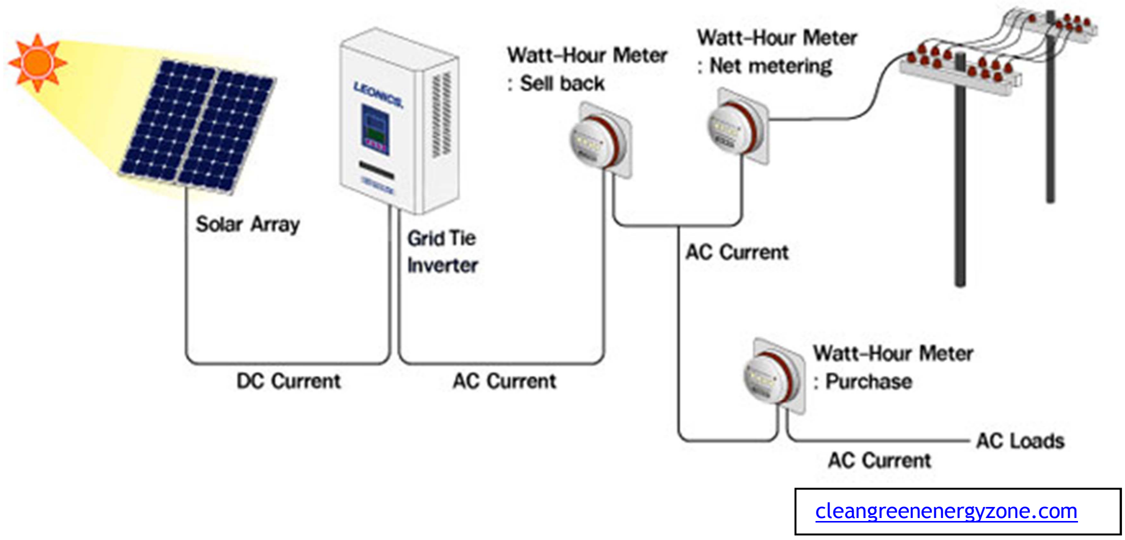


Figure 1 Solar array system components

Each block of PV arrays requires an inverter and transformer. The inverter changes the direct current generated by the solar cells to alternating current that is used in the transmission grid. The transformer steps up the voltage of the PV panel output to a medium-voltage collection system voltage (e.g., 34.5 kilovolts [kV]). The medium-voltage collection system lines that transmit power from each PV block would be buried underground and connected to the project substation. At the substation, the output would be stepped up to the existing transmission system's voltage (e.g., 230 kV).

There are several types of CDOT assets within or near the highway ROW that can accommodate various types of solar array systems such as roof mounted systems on rest areas or maintenance facilities or in combination with noise walls in urban areas. This report focuses upon ground mounted systems which come in various configurations and are more appropriative for the unused physical characteristics of highway ROW areas.

Existing Right of Way Alternative Energy Resources. CDOT maintains 9,144 linear miles of roadway right-of-way (ROW) and numerous other properties including rest areas, maintenance yards, remnant parcels and offices complexes. Colorado's unique characteristics of more than 300 days of sunshine per year; productive wind areas; locations of geothermal activity; areas with grasses, timber and crops; and mountainous areas with fast-moving streams are conducive to alternative energy production from solar, wind, geothermal, biomass and hydropower systems.

In the Study entitled "Assessment of Colorado Department of Transportation Rest Areas for Sustainable Improvements and Highway Corridors" (CDOT Applied Research, 2011), GIS based maps were prepared for the entire State of Colorado to show the location and distribution of potential alternative energy resource locations.

© ASCE 2014

For wind and solar resources, mapping was also prepared for each of the six CDOT Regions to provide more detail on ROW locations and resource distribution.

Literature Search. The literature search involved searching for reports published by various transportation and energy organizations such as the Transportation Research Board (TRB), National Renewable Energy Laboratory (NREL), the Federal Highway Administration (FHWA), Oregon Department of Transportation (ODOT), CDOT and national and international professional organizations. National Environmental Policy Act (NEPA) Environmental Assessments and feasibility studies were reviewed. Overall there is limited research available on evaluating the impacts of solar array system installation and operations on highway ROWs.

Direct discussions and feedback were obtained from CDOT representatives during several meetings. These meetings were conducted with CDOT maintenance, environmental, safety and ROW management representatives. These meetings provided the CDOT participants an overview of the project goals, objectives and approach.

The Research Team coordinated meetings and visits with organizations who have implemented Solar Array Systems within or near highway ROW areas. The RESEARCH Team visited Denver International Airport (DIA), the Northwest Parkway Toll Authority and the Federal Center in Golden (adjacent to US 6). These site visits were invaluable in gaining insight on actual and realistic impacts that may occur with solar array systems in the ROW.

Field study locations were selected along Interstate 70 (I-70), Interstate 76 (I-76) and Interstate 25 (I-25). The I-70 and I-76 solar array model locations were identified by CDOT during initial CDOT scoping discussions. The Research Team conducted the field site visits and observed the site conditions, physical characteristics and evaluated modeling variables to validate the information collected during literature search and expert interviews.

DOTs, FHWA and research institutions have been investigating and implementing solar array system projects to build in sustainable environmental components into their infrastructure based on utility economics. Although implementing solar array systems might be a challenging issue for critical highway operations, it is technically plausible to harvest the available ROW renewable energy potential with respect to all system impact restrictions.

Maintenance and Operations ROW Requirements. Traffic flow, road maintenance, user safety and environmental resources are the major functional components for highway infrastructure operation and maintenance in Colorado. The following is a list of the ROW requirements based on road operation and maintenance (CDOT 1979):

© ASCE 2014

- Snow removal during winter and mowing during summer are the maintenance requirements in addition to repairing pavements and structures. CDOT follows the AASHTO guidelines as applicable.
- Since the maximum speed limit is 75 mile per hour (mph) on the interstate freeway, Clear Zone is an open space 30 feet from the edge of pavement that allows drivers to recover in case the vehicle becomes out of control and run off the roadway.
- Work zone and maintenance: lane shift and reduced speeds are some of the characteristics of a work zone. The use of existing frontage roads and other access roads is desirable for solar array maintenance access. Traffic Management Plans are often required by CDOT for construction and some maintenance actions within the ROW.

Highway ROW Design Requirements. CDOT has a responsibility for safe and efficient flow of traffic along highways; consequently, the safety of drivers and maintenance work crews is vital for CDOT. To help avoid accidents, it is necessary to identify a general design approach for renewable energy installations (REI) near the roadway. The existing AASHTO Roadside Design Guide (RDG) does not have a direct provision for REIs, but assumptions can be made based on the guidance provided for locating units that are associated with REIs, such as array system location, transmission, and grid connection. The following are basic ROW design terms or requirements that are frequently used in this report (AASHTO, 2011):

- The Clear Zone is defined by the RDG as "the total roadside border area, starting at the edge of the traveled way that is available for an errant driver to stop or regain control of a vehicle. This area might consist of a shoulder, a recoverable slope, and/or a non-recoverable, traversable slope with a clear run-out area at its toe." Most highway agencies try to provide at least 30 feet of Clear Zone (traversable and unobstructed roadside area) for high-volume, high-speed roadways.
- Crash Cushions are systems that mitigate the effects of errant vehicles that strike obstacles, either by smoothly decelerating the vehicle to a stop when hit head-on, or by redirecting the errant vehicle.
- Guardrails help guide the off track vehicle back to the road which might be flexible or rigid. Solar array systems should be sited behind existing roadside barriers such as fixed or cable guardrail or crash cushion. This type of barrier would protect the driver and help decrease the severity of accidents from head on collisions with the solar array arrays.
- Fixed/Permanent Applications (such as solar array systems) must be adequately immune to the effects of ambient conditions (e.g. ice and wind loads, temperature) and meet or exceed the AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals.
- Breakaway design features allow a device such as a sign, luminary, or traffic signal support to yield or separate upon impact. The release mechanism may be slip plane, plastic hinges, fracture elements or a combination of these elements.

© ASCE 2014

- To avoid the need of using poles near the roadway, the RSDG suggests burying utility lines when possible. The State Highway Utility Accommodation Code serves as a guideline for safe, efficient and effective joint utilization of State Highway Right of Way (SH ROW) for both transportation and utility purposes (CDOT, 2009).
- It establishes a consistent statewide process for accommodating utilities.

Federal Regulations and Standards. The deployments of solar array systems along the highway ROW are a new development and need to abide by the standards for accommodating utilities on the ROW. The following includes the Federal regulations and standards that must be followed while accommodating utilities in the State Right of Way (as defined in 23 CFR 645.207.):

- "Rights of Way," [Title 23 - Highways] 23 CFR 1.23, April 1, 2008
- "Utility Relocations, Adjustments, and Reimbursement," 23 CFR Part 645A, April 1, 2008
- "Accommodation of Utilities," 23 CFR Part 645 B, April 1, 2008
- Air Space Lease 23 CFR 710

The National and Industry standards in the Rules & Regulations guide require that the all agencies adhere to the following:

- "A Guide for Accommodating Utilities within Highway Right-of-Way," AASHTO, October 2005 Edition
- "Roadside Design Guide", AASHTO, 4th Edition , 2011

Solar array system projects within an interstate ROW must conform to applicable federal regulations and standards cited above. FHWA has developed guidance on the installation of renewable energy in the ROW. FHWA will allow for the accommodation of renewable energies within the ROW only when the facility does not impede the safe and efficient operation of the highway. If this can be achieved there are two options in which projects can proceed via a utility accommodation and an airspace lease.

Utility Accommodation

A utility is determined to be "public" by how a state defines the term under its own laws and regulations as well as whether it meets the Federal definition. As defined in Federal regulation, a utility is a "privately, publically, or cooperatively owned line, facility or system for producing, transmitting, or distributing communications, cable television, power, electricity, light, heat, gas, oil, crude products, water, steam, waste, storm water not connected with highway draining, or any other similar commodity, including any fire or police signal system or street lighting system, which directly or indirectly serves the public" (23 CFR 645.207).

DOTs can accommodate public and private utility facilities within the ROW when such facilities serve the public interest under their approved Utility Accommodation Policy (UAP) Manual or Plan (per 23 CFR 645 Subpart B). The UAP describes practices and procedures for regulating and accommodating utility facilities along,

© ASCE 2014

across, or on highway ROW and other transportation facilities under their respective jurisdictions.

Airspace Leasing

The use of highway ROW to accommodate facilities that will serve private or proprietary interests may also be accommodated; however, it is necessary for them to be approved under the airspace leasing requirements of 23 CFR 710 Subpart D. The right to use the ROW for interim non-highway use may be granted in airspace leases as long as such uses will not interfere with the construction, operation or maintenance of the facility; anticipated future transportation needs; or the safety and security of the facility for both highway and non-highway users. The DOT shall charge current fair market value or rent for the use of the land; the income received from airspace leases shall be used for transportation purposes (as specified in 23 CFR 710.403(e)). Federal regulations do provide an exception to charging fair market rent if the DOT shows and the FHWA approves, that such an exception is in the overall public interest for social, environmental, or economic purposes (US DOT, 2012).

According to DOT-NEPA requirements, each action in the highway ROW that is classified as a potential major Federal action must comply with NEPA requirements and other relevant environmental regulations. The appropriate NEPA class of action is determined by the significance of the environmental impact of the project under study. Actions in the highway ROW that do not individually or cumulatively have a significant effect on the environment, for example, may be covered under a Categorical Exclusion level document (US DOT, 2012).

RISK BASED IMPACT ANALYSIS

Levels of severity (threat) as well as occurrences of a number of potential incidents provide a mechanism to determine the total risk imposed by a factor. A mathematical model called a Risk Impact Matrix was developed for the project by incorporating risk factors, severity, and probability of occurrence. This risk based approach follows the basic Failure Mode and Affect Analysis (American Society of Quality, 2014).

The Risk Impact Matrix is a quantifiable measurement of various ROW factors that are potentially impacted by the solar array system within and outside the ROW. Risk factors are identified based on research literature and internal and external CDOT expert opinion. Impact is assessed in terms of the solar array system's effect on motorist's safety, environmental resources, and ROW operations and maintenance.

Severity of a risk factor is determined based on its harmfulness to a receptor. To choose the most appropriate domain for the identified risk, the severity of a risk used for the project is assessed on a scale of 1 to 100 and is used to develop an impact score, which is expressed as follows in Equation 1:

© ASCE 2014

$$\text{Severity} = \begin{bmatrix} 100\ \text{(fatal)} \\ 75\ \text{(permanent damage)} \\ 25\ \text{(temporary damage)} \\ < 25\ \text{(unnoticeable)} \end{bmatrix} \qquad \text{Equation 1}$$

As shown in Equation 1, within a safety context a severity of hundred is fatal and numbers in the range of 75, 25 and below 25 represent unrecoverable injury (potential permanent damage), recoverable bodily injury (minor damage) and unnoticeably small effects, respectively. If any factors impose a severity of 25-100, a mitigation measure should be considered.

The frequency of harmful incidents expressed as probability of occurrence is another risk-based criterion. As shown in Equation 2, the probability of occurrence is determined based on the number of possible incidents within a life cycle (25 years) of a typical solar array system, which is commonly used as a project life in solar array development.

$$\text{Probabilty of occurrence}(\%) = \frac{\text{Total number of incident hours}}{\text{Total project life (hours)}} \qquad \text{Equation 2}$$

Severity and probability of occurrence are used in the Impact Matrix to calculate the total risk score of a given risk factor to a receptor for a specific site. As shown in Equation 3, the total risk score is the product of severity and probability of occurrence. The product of the two variables is meant to account for the potential cascading impacts and also provide a greater resolution in the results.

$$\text{Total Risk Score} = \text{Severity X Probability of Occurance } (\%) \qquad \text{Equation 3}$$

Based upon the severity, frequency of occurrence and the resulting total risk score for each risk factor identified by CDOT as a concern or in the literature review, a Risk Impact Matrix was developed. This Matrix is a decision making tool for CDOT representatives when energy development is being considered within a CDOT ROW.

Based upon the scope of this research project, the areas for potential solar array locations focused upon I-70 to the Kansas State line and I-76 to the Nebraska State Line. In addition, the solar array system developed by the United States Air Force Academy adjacent to I-25 was observed and evaluated. These research field study locations were selected based upon the following criteria:

- Total available ROW width beyond the Clear Zone
- Greater than 200 feet of ROW
- Rural setting that would model an actual energy development scenario within CDOT ROW
- Areas that have the space to accommodate Solar Array Systems up to a 2.5 megawatt (MW) capacity

© ASCE 2014

Solar Array System Risk Impact Matrix. From the literature and field study it is clear that solar array systems offer tremendous benefits to Energy Developers and/or CDOT with some impacts and risk to driver safety, CDOT Maintenance and environmental resources. The Risk Impact Matrix was developed to identify, quantify and compare potential risks. This Risk Impact Matrix can be an important tool toward aiding CDOT in managing their ROW if a solar array system is constructed and maintained. The Risk Impact Matrix provides the user the following information:

- Total Risk-contains risk factor values that are based on the product of severity and probability of occurrences of an individual factor (see below). The maximum range for total risk is 1-100 with 1 being the lowest total risk value.
- Severity Factor- defines the severity of the human, operational or environmental impact.
- Probability of Occurrence Factor- is a mixture of quantitative probability and best professional judgment. It is essentially the probability that a given event may occur within a given timeframe.

CONCLUSIONS

Highway Right of Way areas are becoming recognized as potential alternative energy resources to many state DOTs. In an era of limited state DOT budgets, ROW areas can be a source of income to DOTs for alternative energy development, especially in the area of solar energy. State DOTs and private Tollway Authorities have been leasing ROW areas to energy providers to offset carbon footprint emissions or obtain financial resource through long term lease agreements.

Highway ROW areas have physical and topographical characteristics that complement the generation of solar energy in the following areas: 1) vegetation is well maintained by operation and maintenance professionals, 2) easy access, 3) generally follow electrical utilities, 4) generally absent of trees or objects that can obscure sunlight, 5) limited site security, and 6) non-developed land that can be located in rural and urban areas.

Based upon the Risk Impact Matrix results for the I-70/I-76 model areas, the following are the major risk factors that should be considered by energy developers and CDOT Management associated with the construction and operation of solar array systems in the CDOT ROW:

- Snow drifting and deposition
- Glare/glint from solar panels
- Water quality management (construction and post construction)
- Noxious weed control
- Driver safety associated with solar array structure collisions
- Driver awareness and expectation
- Access permitting and safety during solar array maintenance

© ASCE 2014

- Wildlife attraction, migration and habitat
- Grass mowing operations
- Snow plow blast during snow removal operations

To address driver safety associated with solar array structure collisions with out of control vehicles, the research project performed a traffic accident assessment along I-70 and I-76. The ROW areas that were assessed were representative of solar array locations within the ROW away from the Denver metropolitan area and with wider ROW areas. The data was reviewed to determine how may vehicles lose control and enter the area beyond the ROW Clear Zone where a potential solar array structure would be established. There were a minor number of situations where vehicles went off the road due to driver fatigue or falling asleep at the wheel and other types of accidents; however, the actual number of vehicle going beyond the Clear Zone was not documented by the accident data.

The mitigation strategies to address risk impacts were developed for CDOT management and prospective energy providers.

REFERENCES

American Association of State Highway and Transportation Officials (AASHTO). (2005). A Guide for Accommodating Utilities within Highway Right-of-Way. *AASHTO Technical Committee on Geometric Design,* Washington, DC

American Association of State Highway and Transportation Officials (AASHTO). (2011). Roadside Design Guide 4th Edition, Washington, DC

American Society of Quality (2014), Failure Mode Effects Analysis, http://asq.org/learn-about-quality/process-analysis-tools/overview/fmea.html,

Colorado Department of Transportation (CDOT). (1979). "Roadside and Drainage Maintenance." *Highway Maintenance Manual*

Colorado Department of Transportation (CDOT). (2009). "Rules and Colorado Department of Transportation (CDOT). (2008). Rules and Regulations of the Colorado Deparment of Transportation Pertaining to Accommodating Utilities in the State Highway Rights of Way"., 2C.C.R. 601-18

Colorado Department of Transportation Applied Research and Innovation Branch. (2011). "Assessment of Colorado Department of Transportation Rest Areas for Sustainable Improvements and Highway Corridors"

Code of Federal Regulations (CFR) (2000). Title 23 Highways; Part 645 Utilities, Washington DC

Code of Federal Regulations (CFR) (2008). Title 23 Highways; Part 700 Right of Way and Real Estate, Washington DC

Tribal Energy and Environmental Information. (2014). "Solar Energy Descriptions". http://teeic.anl.gov/er/solar/restech/desc/index.cfm (Feb. 15. 2014)

United States Department of Transportation (US DOT). (2012). Alternative Uses of Highway Right-of-Way"; *Accommodating Renewable Energy Technologies and Alternative Fuel Facilities*; Prepared by Research and Innovative

© ASCE 2014

Technology Administration, John A. Volpe National Transportation Systems Center, Cambridge, Mass

© ASCE 2014

Effectively Addressing the Risks to the Infrastructure Presented by Extreme Hazards: The Need for a Shift in the Design Paradigm

Garry D. Myers[1] and John E. Crawford[2]

[1]MKC Global Protection, Inc., 700 N. Brand Blvd, Suite 750, Glendale, CA 91203-3215, USA;
Tel: +01 818-844-1866; Email: gmyers@mkcglobalinc.com
[2]Karagozian & Case, 700 N. Brand Blvd, Suite 700, Glendale, CA 91203-3215, USA;
Tel: +01 818-240-1919; Email: crawford@kcse.com

ABSTRACT
The risk of extreme damage to critical facilities by attacks from terrorists or disgruntled employees combined with process risks is becoming a major factor in the design. The approach suggested by extant practices and guides with this regard has evolved into a pseudo-design methodology involving missing columns and "tie force" designs and detailing. Very different design concepts are needed to analyze structures that are highly damaged or have failed completely. The New Design Paradigm focuses on component design of critical building elements using a threat dependent, performance based methodology using high-fidelity physics-based (HFPB) finite element codes that capture actual material and component response. One of these is LS-DYNA developed by Livermore Software Technology Center. To counter the difficulty, expense and high degree of skills needed for use of HFPB codes one approach is to develop and use a library of Fast Running Models (FRM's) which interrogate a database of virtual HFPB response data for given components and loading. These FRMs can be rapidly and easily run on desk top computers and can provide access to a domain of solutions far outside the capability of simplified engineering tools for a range of loading scenarios such as air blast loading from high-explosive detonations, vapor cloud explosions and primary and secondary fragmentation. Component design using HFB codes and FRMs for speed and economy of analysis will provide a far more meaningful analysis for blast effects, including disproportionate collapse than simplified methods advocated in the Unified Facilities Criteria (UFC) and similar design guidance documents.

INTRODUCTION

Giving due consideration to the design of key elements in the infrastructure for risks emanating from extreme hazards, such as might be presented by attacks from terrorists or disgruntled employees, is becoming a major factor in the design of many types of facilities. In this regard, professional organizations and extant design guides have not done a good job of combining good design practices with the kinds of new design concepts and analysis procedures that are needed to effectively and rationally

© ASCE 2014

address the sorts of extreme and rare hazards that are presented by blast and disproportionate collapse. These deficiencies are rooted in issues dealing with cost, software availability and training of engineers. This is in marked contrast to the best practices and design guides that are regularly and successfully employed in present day design for the more normal sorts of hazards such as wind and seismic (e.g., the ACI manual) that work well in incorporating into the design process the considerations required to address natural hazards.

CURRENT APPROACHES

Recent efforts to develop a more robust design paradigm to resolve the difficulty of generating designs suitable for mitigation of malicious, extreme and exceedingly rare (MER) threats within a conventional design practice need to be given a serious reality check, especially in terms of whether designs based on such guides/practices realize the protection promised and do so at a reasonable cost without excessively intruding on the operational and architectural features of the facility.

The approach suggested by extant practices/guides is far from ideal and has devolved into a sort of pseudo-design methodology that is largely based on ad hoc and outdated ideas for the design of blast-resistant structural members, embodying a process, while easy to implement, whose soundness and efficacy is unproven and of seemingly little regard. As a result, designs are realized in a way that sacrifices capability over expediency and that fail markedly in achieving the most bang for the buck (pun intended), and sometimes even increase the risks.

The design approaches of tie force/missing column advocated by the Unified Facilities Criteria (UFC) neither represent a soundly based risk management approach nor even good design practice. Structural engineering simplified engineering tools, advocated by the UFC, are not effective and beyond their capability when addressing the kinds of response complexities that are present in framing systems when subjected to the sorts of damage scenarios suggested by design guides that pertain to adding collapse resistance to a framing system.

WHAT NEEDS TO BE DONE

Effectively addressing the difficult to predict risks presented by MER threats must acknowledge that such events occur at such a low probability and generate such high magnitude impact that skews traditional measurements of risk. Therefore, a design approach that puts resilience and “fail safe” at its core, rather than as an independent measure may be a more sensible approach to delivering safer infrastructure. Very different design concepts and analysis procedures are needed to analyze structures that are highly damaged or have failed completely and to have the ability to rank the importance/occurance of the hazards and provide cost-effective designs that are based on “the principal of good-enough” (POGE).

A new design paradigm is needed that primarily employs a POGE approach to design rather than the “100% sure” followed in design for natural hazards, such as wind and earthquake. The POGE standard is in recognition that no design standard (e.g., in terms of specific blast loads) has a basis in reality. To ensure that false opti-

© ASCE 2014

mums are avoided, the capability and risks presented by a particular protective design should be assessed for blast loads above the design load. This avoids one of the most peculiar aspects of this sort of design, which is that the risk can actually be exacerbated by protective design that too narrowly addresses the risks.

Finally, the influence on the design paradigm of the analysis capability afforded by conventional finite element codes (e.g., SAP) must be a part of the design practices adopted. Current technology presented by these codes offers poor support to the design process for extreme, low-probability hazards. The sorts of FE codes that can address these problems are at present too difficult to operate effectively by even highly competent engineering-design firms. In this regard, only a few specialists and at considerable expense can perform such analyses. Thus, the capability and ease of use of the analytic process should play a major role in new design paradigm developed.

THE NEW DESIGN PARADIGM

The **New Design Paradigm** will encourage a focus on component design (as opposed to system design) of critical building elements identified through an assessment of global response modes and vulnerabilities. Addressed will be both regular framing systems and irregular systems that are often present on iconic, high value buildings likely to be terrorist targets. For example, rather than undertaking large and complex analyses of building systems using alternate path (AP) or tie force (TF) approaches, as is advocated by current design guides including UFC 4-023-03, the blast engineer will look at critical exterior (columns, spandrel beams) and interior building components (columns, slabs and connection systems) and evaluate/design them on their ability to resist different types of extreme hazards. For example, for determination of blast hazards, the use of different charge sizes and standoff protection with appropriate factors of safety against collapse, as illustrated below.

Table 1. Blast hazards based on charge size

Type of Charge	Level of Protection	Frequency of Event
Truck Bomb	Very Low (VLLP) to prevent progressive collapse (PC)	Massive and infrequent Well-designed structures should survive.
Car Bomb	Low (LLP)	Large & more frequent. Less threat to structure unless little standoff.
Person Borne (PBIED)	Medium (MLP) Local repairable damage.	More likely. Special protective schemes needed for near contact

The methodology of hardening components offers an analysis and design approach that is not too costly or onerous to undertake and, if properly implemented, will result in an acceptable level of residual risk. Crucially, this is also an approach that practicing engineers can effectively and ubiquitously apply. A critical element of this approach is the requirement for a threat dependent (or performance based) de-

© ASCE 2014

sign, in marked contrast to the threat independent approach currently advocated in government design guidelines. It is not unreasonable or indeed currently uncommon, for 'design threats' to be identified however, once identified, there is little thought dedicated to how they might be manifested, their actual effect and what mitigation measures might be adopted. Instead, current guidance documents choose to ignore the threat specifics and apply generic requirements for structural performance.
As a part of a threat dependent/performance based design, an integrated planning approach is required to reduce the threat and maximize structural resilience. Appropriate steps include the following:

- Determination of design threats including relative magnitude and likelihood.
- Assessment of structure/site and identification of opportunities to mitigate threats through active (guard force etc.) and passive (vehicle barriers etc.) measures. Some examples might be:
    - Control of employee vehicles and isolation of visitor parking
    - Channelization of pedestrians to authorized areas or entrances.
    - Provision of vehicle barriers around the facility at established setback distances.
    - Utilize hardened glazing systems designed to reduce the glass fragmentation hazard.
- Where the risks associated with the design threats cannot be reduced to an acceptable level engineering effort is required to provide resilient and redundant structural systems and connection/detailing through the design of robust components.

With this design philosophy in place to minimize the threats, there are many documents which can be used to offer design guidance including:

- The Interagency Security Committee Standard "Physical Security Criteria for Federal Facilities" (commonly known as the ISC),
- Veterans Administration Physical Security Design Manuals,
- DoD "Minimum Antiterrorism Standards for Buildings"
- Other design manual and documents prepared by the American Society of Civil Engineers – ASCE
- Unified Facilities Criteria (UFC) document "Design of Buildings to Resist Progressive Collapse.

This process will require transforming the hazards presented by extreme accidental or malicious events into loadings suitable for structural analysis and then effectively capturing the resultant structural response. To do so will require utilization of analytical tools that actually incorporate the physics and responses of the components and are easily understood by practitioners. These tools are currently developed by three disconnected communities: academic and research institutions developing struc-

© ASCE 2014

tural theory, software and design tool developers and practicing engineers. Finite element codes that are currently advocated by the collapse design guides, such as SAP, are not up to the task assigned to them in these guides and are being used in a manner not intended by their developers.

A longer term goal should include bringing research and knowledge used in our educational and research institutions current with the efforts of industry to improve the state of the art combined with better training and certification of analysts. A more formal program to satisfy these needs is required to effectively address structural and material problems pertaining to extreme loading environments.

Currently many computational tools are available for component analysis and design starting with simplified-engineering (SE) models using single degree of freedom (SDOF) procedures which have proven quite effective in forecasting component response and behavior for 'far-field' blast events. However, the characteristic threats encountered within the protective design industry, particularly those with malicious intent, are more commonly 'near-contact' or 'contact' in nature, for which SDOF analysis is not applicable [despite the regularity with which it is negligently applied in these scenarios – further developing the case for client enlightenment]. Consequently, computational methods that capture actual material and component response are required and these can be broadly categorized as high-fidelity physics-based (HFPB) finite element codes, of which LS-DYNA, developed by the Livermore Software Technology Center (LSTC), is the most well-known. LS-DYNA offers a variety of solvers for continuum mechanics equations, which provide the sort of flexibility and material properties required to solve complex blast effects and penetration analysis problems.

Enhancement of these HFPB codes, especially for the contact and near-contact scenarios described earlier can be achieved through 'coupling' the Computational Structural Dynamics (CSD) codes, such as LS-DYNA, with Computational Fluid Dynamics (CFD) codes. This coupling provides most benefit where the response of a component/structure is interacting with the propagating air blast. A ready application might be the analysis of the effects of air blast loading from a PBIEDs on a steel column as the web and flanges deform.

As the deformation and damage of components becomes more pronounced, as is likely with the localized damage associated with near-contact detonations, even advanced tools such as LS-DYNA, which rely on Lagrangian-meshes are unable to produce valid results and adoption of mesh-free, particle methods is required. KC-FEMFRE is an example of such a tool which utilizes particle methods to avoid the mesh-related issues associated with significant distortion/deformation.

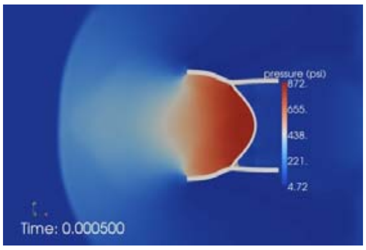
Following discussion of these tools, it is now easier to appreciate how far from SAP or SDOF methods we have needed to reach in order to effectively capture these behaviors, and yet they remain the foundation of the design codes applicable to this area of study – surely a **New Paradigm** is required.

However, we cannot and should not expect our mainstream practitioners to be conversant in these HFPB codes as they are cumbersome, relatively expensive to operate and require a high degree of technical skill and experience to operate effective-

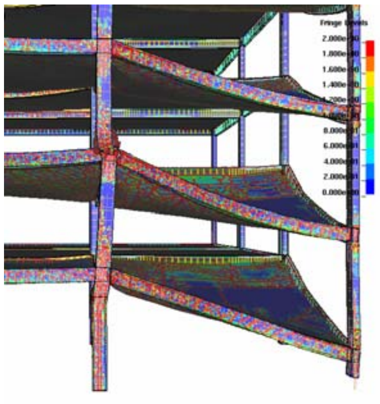
© ASCE 2014

ly. In fact, the 'have-a-go' approach currently being exhibited by a number of reputable engineering contractors in an effort to demonstrate a broader capability is both technically and professionally ill-advised and should be discouraged. The challenge is to leverage the analysis power of the HFPB tools into a format suitable for use by the engineering mainstream?

One approach is the utilization of so-called Fast Running Modes (FRMs) which interrogate a database of virtual HFPB response data for given a component and loading. These FRMs can be run in seconds on normal desktop computers and provide access to a domain of solutions far outside the capability of simplified engineering tools, especially for the near-contact detonation events already discussed.

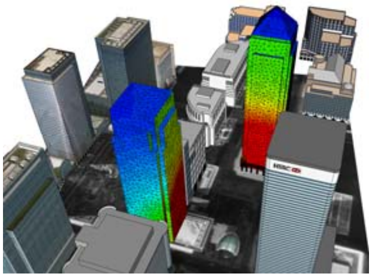


Coupled CFD/CSD Analysis

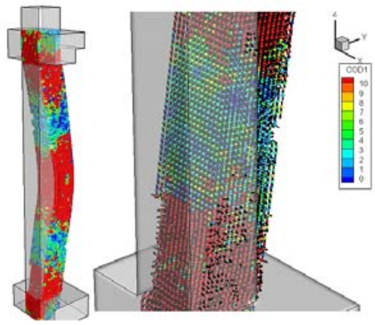


Disproportionate Collapse HFPB Calculation

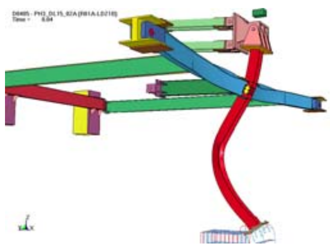
Comparison of HFPB calculations and test behaviour



Urban Landscape Analysis



Meshfree analysis indicating material damage



Component response well outside the capability applicability of simplified engineering tools

Figure 1. Examples of HFPB calculations

Although developed for military applications (the standard genesis for such tools), FRMs could be expanded to include libraries of common structural component models, including dimensional and material parameters as well as a range of loading scenarios such as air blast loading from high-explosive detonations, vapor cloud ex-

© ASCE 2014

plosions and primary and secondary fragmentation. Once these libraries have been established, an engineer is able to simply input the parameters applicable to the design task under consideration. The FRM then interrogates the virtual data and selects the corresponding response behavior as an analysis output.

Component design using HFPB codes and FRM's for speed and economy of analysis will provide a far more meaningful analysis for blast effects, including disproportionate collapse than simplified methods advocated in the UFCs and similar design guidance documents. The results obtained therein can then be combined with conventional structural engineering design services for seismic, wind, and gravity loads based on conventional design guides and codes.

The level of effort in this regard will be far less costly and complicated to implement and more likely to achieve a much improved outcome than the current efforts to use system analysis tools to assess the behavior of the building and framing systems as a whole in extreme loading environments. Indeed, the capability of computational analysis tools now available to practitioners has brought about a 'tipping-point' whereby higher fidelity analysis can be delivered at costs which make compelling cost-benefit arguments from the associated construction and material savings. This trend will continue over the coming years and the **New Design Paradigm** seeks to exploit this opportunity rather than stymy its evolution through reliance on dated computational analysis methods.

In order to implement the **New Paradigm** practicing engineers require the professional liability issues to be addressed more effectively. The segregation of the experts in this specialty field; i.e. practicing engineers, code and software developers and government bodies has resulted in a design environment where responsibilities are difficult to assign. These issues are exacerbated by the difficulty of the assignments and inappropriate use of software by those with inadequate experience, knowledge and skill in this highly complex field.

© ASCE 2014

The South Los Angeles Wetland Park – Achieving the Triple Bottom Line

A New Paradigm in Sustainable Public Urban Infrastructure

Sean P. Vargas, P.E., ENV SP, LEED AP[1] and Shahram Kharaghani, PhD, P.E., BCEE[2]

[1]Psomas, 555 S. Flower Street, Los Angeles, CA 90071; PH (213) 223-1516; FAX (213) 213-223-1444; email: svargas@psomas.com
[2]City of Los Angeles, Department of Public Works, Bureau of Sanitation, 1149 S. Broadway, 10th Floor, Los Angeles, CA 9001; PH (213) 485-0587; FAX (213) 485-3939; email: shahram.kharaghani@lacity.org

ABSTRACT

The 10-acre South Los Angeles Wetland Park is located in Southern California in a historically underserved area of Los Angeles County formerly known as South Central Los Angeles. Completed in 2013, it is a feature project of Proposition O, a program supported by a series of general obligation bonds valued at $500 million. The multi-benefit, constructed stormwater-treatment wetland facility was conceived to protect public health by removing pollution from the City's watercourses in order to meet Federal Clean Water Act requirements.

The Envision™ Platinum Award-winning project represents a bold, integrated engineering solution that successfully built consensus, captured and improved local urban runoff, and created a new neighborhood-revitalizing amenity. It is the result of partnership between a public works department and a consulting engineering team who collaborated to advance the paradigm of multi-benefit public projects.

This paper will provide a case study illustrating how the South Los Angeles Wetland Park embodies the "Triple Bottom Line" of sustainability through its social, environmental, and economic elements.

Background

South Los Angeles is a 51-square-mile region within Los Angeles County, California. Located within the Los Angeles River Watershed, this highly urbanized area is tributary to the Los Angeles River, a predominantly concrete-paved channel that discharges to the Pacific Ocean. The Los Angeles River is a Clean Water Act Section 303(d) listed water body and is subject to Total Maximum Daily Load (TMDL) requirements for criteria pollutants.

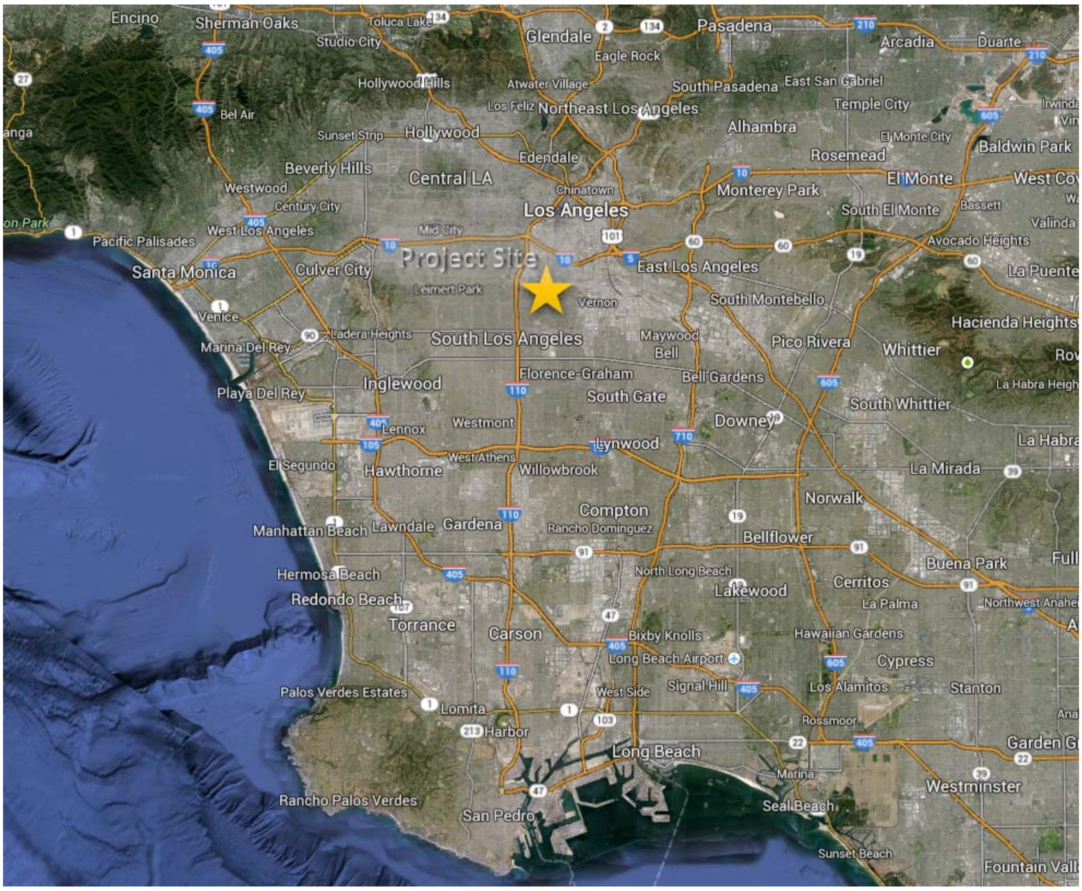


Figure 1. Aerial Site Location

In November 2004, the City of Los Angeles voters passed Proposition O authorizing the City to issue a series of general obligation bonds for up to $500 million to fund stormwater management projects. These projects help to protect public health by preventing pollution of the City's watercourses, beaches and the ocean, in order to satisfy the above-mentioned Clean Water Act requirements.

To ensure transparency the City established an Administrative Oversight Committee (AOC) and a Citizens Oversight Advisory Committee (COAC). In the Fall 2005, the Proposition O program began conducting public workshops to educate the public about the program, as well as to encourage submission of candidate

© ASCE 2014

projects for funding. The City began accepting project applications in October 2005. Projects were evaluated to the extent that they satisfied three general criteria:

- Water quality improvements
- Multiple objectives
- Project feasibility/readiness/financial viability

The program established a framework within which environmentally, socially, and economically sustainable projects could rate highly and ultimately receive funding. The South Los Angeles Wetland Park was one of the first highly-ranked projects proposed.

Project Planning

The initial concept for the project contemplated the creation of a community resource of stormwater treatment wetlands and riparian habitat in a densely populated urban area. The goal was for the wetland park to be a quiet refuge and an amenity to residents adjacent to a new public school and a multi-use community center. In order to achieve this goal, the project would face many challenges including the fact that the desired candidate parcel was an in-use transit maintenance facility. Planning and delivery for a project of this complexity, therefore, required an inclusive approach. The Bureau of Engineering's Proposition O Group, along with the consultant team embarked on a pre-design journey during which time they built a coalition of project partners:

- Los Angeles County Metropolitan Transportation Authority (Metro) – the historic landowner of the (then) active transit maintenance facility
- Bureau of Sanitation - ultimate/future maintenance authority for the stormwater treatment system
- Recreation and Parks Department – the ultimate/future maintenance authority for the public park components
- City Council District Office 9 – active project proponent and facilitator

This "family" of agencies and the consultant team, through partnership, set the wheels in motion for project funding, acquisition of the property, and development of a Memorandum of Understanding (MOU) assigning the perpetual future maintenance and operation responsibilities for the facility.

Due to the innovative nature of the project, it was able to secure funding from an array of sources, including Community Block Grants; site mitigation funding from Metro; Propositions 12, 40, 50, and K; and the Baykeepers SEP settlement.

Beginning in the planning phase, an Environmental Impact Report (EIR) was prepared consistent with California Environmental Quality Act (CEQA) requirements. The site was deemed a Brownfield by Supplemental Site Assessment which identified impacts from volatile organic compounds (VOCs).

© ASCE 2014

Public, multilingual presentations and public meetings were conducted within the community during the project planning phase. The project team educated the community about the planned project and received public comment and project input.

Pre-Design Activities

Following the planning phase the project team began preparation of a Pre-Design Report (PDR). The PDR for the South Los Angeles Wetland Park is a 441 page document that in addition to evaluating project alternatives and identifying potential fatal flaws, included the following activities:

Table 1. PDR Preparation Table (Psomas 2008)

Activity	Detail
Studied existing and proposed conditions hydrology and hydraulics	Described tributary subwatershed, evaluated low and high flow stormwater diversion
Evaluated the use of urban runoff as a resource	See detailed discussion below
Performed historical land use and cultural investigations	Identified historic building onsite, developed requirements for cataloguing culturally significant items
Identified supplemental permitting requirements	Identified considerations to "avoid traps" relative to future permitting requirements as the proposed wetland establishes over time
Performed soils investigation	Geologic, geotechnical, agronomic, and subsurface contamination
Documented vector and ecological considerations	Developed vector control approach, considered existing migratory bird flight-path
Described anticipated Operation and Maintenance activities (O&M)	
Identified funding requirements and constraints	Identified budget requirements and funding milestones
Documented community outreach activities	

Urban Runoff as a Resource

The key-factor to the ultimate success of the project, from an environmentally-sustainable stormwater management perspective, was the approach to use urban runoff as a resource. The project is pioneering in that it is the first of its kind in the region to use stormwater runoff as a resource to sustain a natural aquatic surface water system in an urban, Mediterranean climate. Mediterranean climates are characterized by long, hot summer droughts and prolonged wet periods in winter.

Table 2. Monthly Precipitation and Associated Runoff Volume Depth for South Los Angeles (NOAA 2006)

Average Runoff Volume from Contributing Watershed (1921-2006)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Ave. Annual**
Precipitation (in)	3.1	3.4	2.5	1.1	0.3	0.1	0.0	0.1	0.3	0.4	1.4	2.4	**14.9**
Volume (ac-ft)	133.9	149.6	108.5	48.1	10.9	3.5	0.4	2.6	11.8	18.8	59.1	105.0	**652.3**

The unique technical challenge for the team was to design a wetland system that would support the survival of soil biota, flora, and fauna during both the "wet" season as well as the normally "dry" season, and to simultaneously maximize urban runoff treatment year round — on a Brownfield site.

The team developed a water budget that would sustain the wetland in the summer, primarily with "dry-weather runoff", while simultaneously treating 100% of this runoff from the contributing 525-acre subwatershed. In the winter the wetland is designed to rapidly fill the transient storage, and to then also treat "first-flush" runoff from the same subwatershed.

To test the hypothesis that the proposed water budgeting approach would support the summer condition, the team quantified the available dry-weather runoff in the existing 63" diameter subsurface storm drain in the adjacent right of way using ultrasonic flow monitoring equipment.

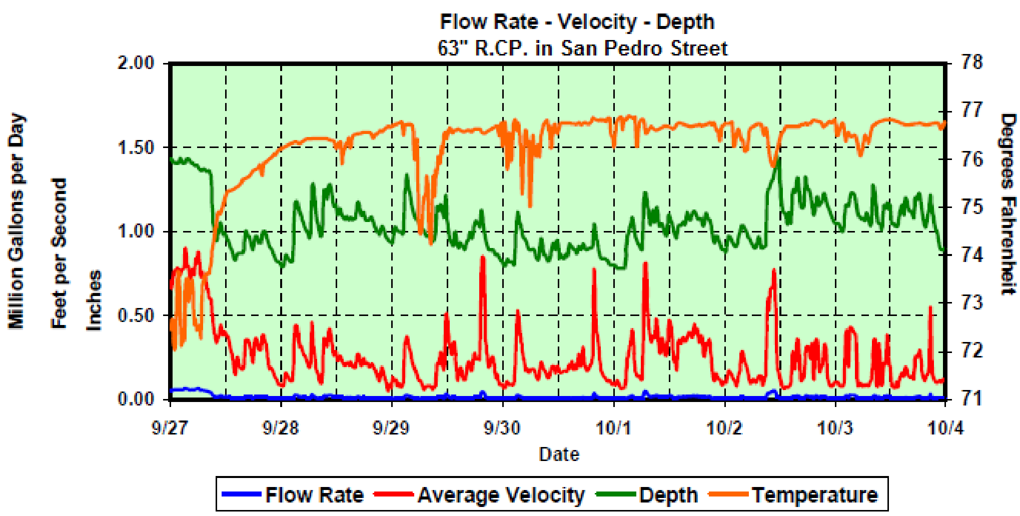


Figure 2. Stormdrain Monitoring Results (Psomas 2008)

© ASCE 2014

The team then estimated the evapotranspirative potential of the wetland based on locally monitored pan data. The wetland size, configuration, and layout were then optimized to also maximize wet-weather runoff treatment potential.

Project Development

In order to satisfy the true multi-benefit mandate established for the project, the Park had to act as a local neighborhood amenity, provide a profound environmental benefit, and represent a catalytic "node" in the revitalization of South Los Angeles.

Figure 3. Urban Oasis

Neighborhood-revitalizing Amenity

Within the neighborhood, land use is primarily residential to the north, east and west of the project site, with three existing churches within 100 feet from the Park.

The project site is located within the established boundaries of the Southeast Los Angeles Community Plan Area. The Southeast Los Angeles Community Plan (Community Plan) describes the specific goals and objectives for this neighborhood. It identifies historic land use issues and identifies which direction the community has indicated it wants to go. According to the Community Plan, this area has seen inconsistent land use developments over the years that have created issues for the community. Among the goals in the Community Plan are the following:

Residential: Encourage preservation of the single-family residential land use in the area.

© ASCE 2014

Commercial: Strengthen and encourage commercial and retail development along the historic commercial corridors to bring back needed services that have left the area.

Open Space: Encourage the development of new open space in the area including the joint development of community centers and schools with recreation space. The Community Plan identified a lack of open space within the area. (Psomas 2008)

A key metric with respect to social sustainability is the degree to which a project respects, or in this case, restores important community assets. The new Park amenity upgrades and extends access, promotes education, and increases safety, consistent with the Community Plan's goals.

Pre-Construction Conditions (2007) **Revitalized Area Post-Construction (2012)**

Figure 4. Conditions Before and After

Community-engaging Park features include:

- Amphitheater-style outdoor classroom
- An educational kiosk and signage describing the Park's function, flora, and fauna
- A recreational walking path around the treatment wetland
- Picnic benches
- Observation bridges and platforms over the wetland itself

The project has helped to reinvigorate the host and nearby communities. Genuine collaboration with the community has elevated community awareness and pride, resulting in a markedly elevated quality of life.

<u>Environmental Benefit</u>

The treatment wetland reduces the introduction of pollutants generated from urban runoff to receiving waters via a series of stormwater Best Management Practices (BMPs). The project BMPs include a combination of structural and "green" elements within the "treatment train".

© ASCE 2014

The treatment train begins within the Right-of-way of San Pedro Street below ground at the existing 63” storm drain mainline which serves the 525 acre contributing sub-watershed. A new low-head-loss, drop-type, diversion structure was constructed to divert urban runoff for use and treatment within the new wetland

To prevent clogging of the wetland’s pump system and the transport of trash, debris, grit, and grease into the wetland itself, structural pre-treatment is provided. Structural pre-treatment elements downstream of the diversion include a trash rack/bar screen and a hydrodynamic separator. Maintenance access to the pre-treatment system is provided via the secured maintenance yard at the northwest corner of the site. After pretreatment, runoff enters centrally-monitored (SCADA) pump sections that have been designed to operate within two distinctly different inflow regimes:

Dry Weather Regime

During the dry season, when urban runoff is at its lowest, all dry-weather-runoff (field measured at an average of 14,000 gpd during PDR investigation) flowing in the mainline in San Pedro Street is diverted to the wetland via the Low-flow pump section: two 3-hp pumps and 3” force main discharge. Diverted runoff enters the wetland via low flow distribution headworks located in the forebay of the wetland. Runoff mixes with permanent pool wetland water, flows through the first wetland cell, and slowly discharges into the downstream cells through a series of control orifices. Influent runoff diffuses pollutants throughout the wetland allowing for mixing and treatment. Aeration also occurs in the forebay to assist with mixing and oxygenation. During the dry season all urban runoff from the 525 acre sub-watershed is captured, treated, and used to sustain the treatment wetland via offset of evapotranspiration-related loss.

Wet Weather Regime

During the wet season the high flow pump section diverts precipitation-event related runoff via (3) x 40-hp pumps and 8” force main discharge to the forebay. During wet-weather events the low flow pumps are de-energized via a programmable logic controller and the high flow pump system is energized. Influent wet-weather runoff is discharged into the forebay, via a submerged energy dissipator, to minimize scour, suspended solids transport, and re-entrainment. During a storm event, runoff is pumped into the wetland until the wetland reaches its maximum transient storage/treatment volume. As the water surface elevation rises in the forebay, water begins to discharge over weirs at the downstream ends of cells 1 and 2.

When the maximum combined treatment volume is reached, redundant ultrasonic/float level controls in the wetland de-energize the high flow pump system to prevent wetland washout. The wet-weather event-related treatment volume is discharged, via orifice, back to the San Pedro drain approximately 72 hours after

© ASCE 2014

wetland fill. High flow pumps are reactivated after a portion of the treatment volume has been discharged via the Cell 3 orifice-regulated discharge.

Figure 5. Cell 1 – Event-Related Weir Discharge

Wetland Treatment

The constructed treatment wetland is a deep marsh (3) cell system with the following habitat regions:

- Open Water Habitat
- Emergent Marsh Habitat
- Riparian Scrub/Woodland Habitat
- Upland Habitat

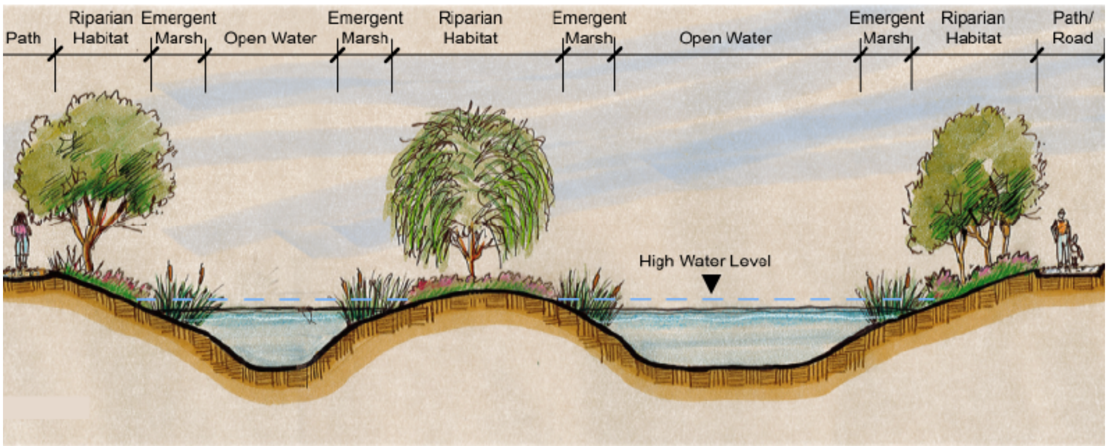


Figure 6. Illustrative Wetland-Cell Cross Section (Psomas 2008)

© ASCE 2014

Open Water habitats include the forebay of cell 1 and all channels and deep pools. Normal water depths are approximately 4 feet in channels and 6 feet in the forebay and pools.

Emergent Marsh habitat is normally inundated with water at depths of approximately 0.5 to 3 feet. The Emergent Marsh habitat is the primary region where the water column interacts with the sediments, biota (algae, macrophytes, bacteria, fungi), and the water/air interface. Mechanisms of water treatment in this habitat include; settling and filtration of suspended matter, volatilization of compounds, adsorption and desorption of compounds from particles, biological uptake and transformation, and photolysis of pathogens.

Riparian Habitats, the transitional areas between the upland portion of the park and the aquatic ecosystem and subject to periodic inundation, occur around the perimeter of the wetland and on the islands of Cell 3.

Upland Habitat occurs above the riparian habitat and outside of the wetland footprint. Many of the characteristic vegetation species of the Upland habitat are woody vegetation and trees that can grow to large sizes with correspondingly large root zones.

Wetland Forebay

The forebay is located in Cell 1 on the eastern portion of the project site. The forebay helps to reduce the velocity of peak flows and allows for secondary sediment removal from the water initially upon entering the wetland.

Wetland Cells

The use of multiple cells allows for flexible operation and maintenance of the wetland system, residuals clean-out, maintenance of flow control structures, and general upkeep without disruption of the overall system. The subsurface hydraulic distribution from the pump station has been designed such that any cell may be isolated via manual operation of a network of gate valves along the force mains.

From a water treatment standpoint, multiple cells, as configured, help provide better treatment in part because "short-circuiting" of the wetland is minimized. Short circuiting in a constructed wetland can occur when influent water bypasses much of the wetland area and flows out of the wetland system in a time shorter than the design residence time. By subdividing the constructed wetland into several we have minimized the potential for short circuiting. Together, the three cells provide a total wetland length of approximately 1,200 feet and width of 450 feet and a lined footprint area of approximately 4.5 acres. The side slopes for the riparian habitat are 5:1 (20%), while the emergent marsh area varies from 3.5% to 20%. The side slopes of the permanent pools are designed with a 2:1 slope (50%).

© ASCE 2014

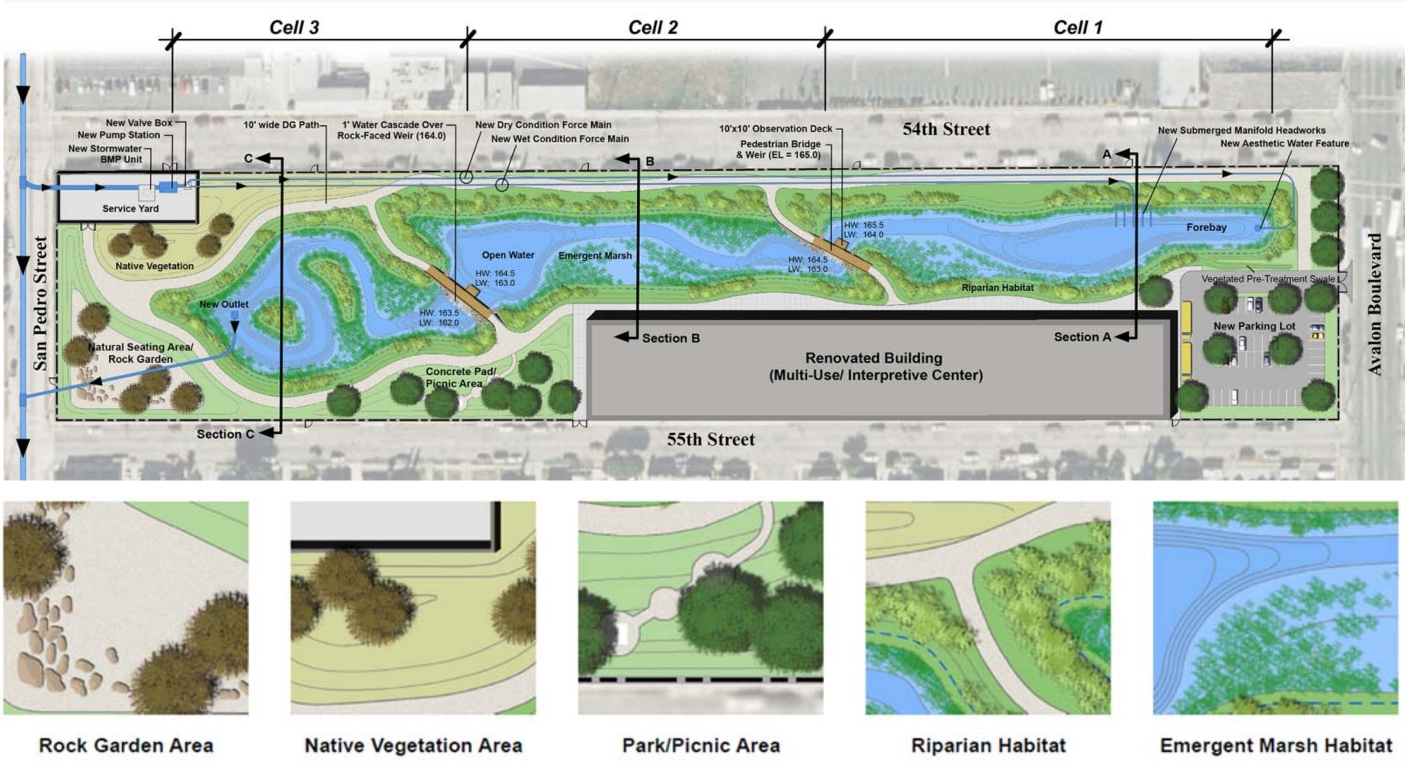


Figure 7. Treatment Wetland Schematic Plan-View Illustration (Psomas 2008)

Aeration

Natural processes of respiration and degradation in a wetland system tend to decrease the level of dissolved oxygen (DO) in the water column. If levels of DO are not replenished, significant portions of the wetland can become anoxic thereby promoting anaerobic conditions. This scenario is most likely to occur during the summer months when runoff baseflow through the wetland is at its lowest. Deficiency of DO has been mitigated through installation of a water feature in Cell 1.

Impermeable Liner

Because the soil materials on-site are generally sandy and no subsurface natural clay layers occur on the project site at shallow enough depths to prevent infiltration/water loss from the wetland, coupled with the fact that the site is a historic Brownfield, an impermeable liner system was required. All three wetland cells are lined with a geosynthetic clay liner (GCL) overlaid by a linear low density polyethylene (LLDPE) liner.

© ASCE 2014

The Triple Bottom Line

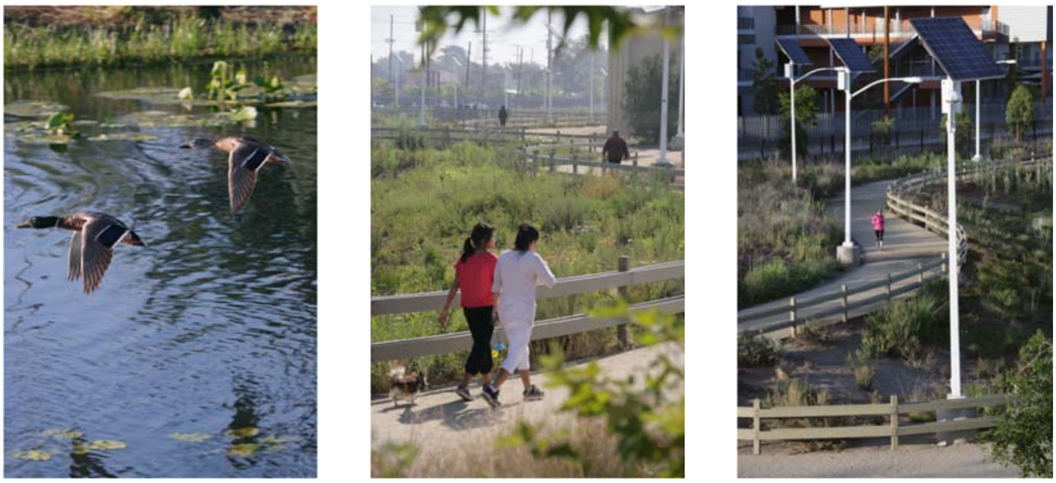


Figure 8. Community Revitalization

The South Los Angeles Wetland Park is the embodiment of the "Triple Bottom Line." The project was conceived from day-one to fully reflect the three pillars of sustainability:

<u>Environmental Considerations</u>
The underlying purpose of the Park itself, as mandated by the main funding source, Proposition O, is cleaning up urban runoff and improving the quality of local receiving waters. The project went above and beyond by selecting a Brownfield site and remediating it. It went further by electing to push boundaries with the selection of an urban treatment wetland as the featured "green" treatment technology in lieu of a far simpler traditional "grey" technology. Finally it created habitat in an area that previously had none. The transformational result includes restored native flora and fauna within an existing migratory bird flight path.

<u>Social Equity Considerations</u>
Again, if stormwater treatment had been the only virtue of the project, an end-of-pipe solution could have been elected. Instead, the stakeholders recognized the opportunity to do something transcendent. Through multi-agency partnership, community engagement, planning, and ultimate execution, we have created a public park where there was a bus maintenance facility; a vegetated oasis where there was only asphalt; a renaissance in an underserved community.

© ASCE 2014

Economic Considerations

The Park is catalytic in its economic impact. It is a showcase of how to get public works projects delivered in an increasingly competitive environment for funding dollars. It leveraged nearly a dozen funding sources. The project was designed to use solar-powered lighting and urban runoff as a resource to reduce the project's reliance on the grid along with the associated costs. Finally, the project, along with the adjacent new high school, is playing a vital role in the economic resurgence in the community.

REFERENCES

NOAA. National Weather Service Forecast Office. Los Angeles/Oxnard Region. http://www.wrh.noaa.gov/lox/climate/cvc.php

Psomas. *Final Pre-Design Report Proposition O South Los Angeles Wetland Park*. Tech. no. 1LOS170500. Los Angeles: Psomas, 2008.

© ASCE 2014

Innovative Modification to Improve Resilience of the Los Angeles Aqueduct after the next San Andreas Fault Earthquake

Michelle Sutherland[1], C.E.G., Jeffrey Keaton[2], F.ASCE, Ph.D., D.GE, ENV SP, Nagamuthu Kuganenthira[3], Ph.D., P.E., G.E., Ray Hamilton[4], P.E., M.ASCE Michael Palmer[5], Ph.D., P.E., M.ASCE, and Bruce Corkle[6], P.E., M.ASCE

[1]Project Engineering Geologist, [2]Principal Engineering Geologist, AMEC Americas, 6001 Rickenbacker Rd, Los Angeles, CA 90040; michelle.sutherland@amec.com; jeff.keaton@amec.com [3]Geotechnical Engineer, City of Los Angeles, Department of Water and Power, 111 North Hope Street, Room 1368, Los Angeles, CA 90012; Nagamuthu.Kuganenthira@ladwp.com; [4]Principal Engineer, AMEC Americas, 2000 S Colorado Blvd, 10th Floor, Denver, CO 80222; ray.hamilton@amec.com; [5]Partner, Elwyn & Palmer Consulting Engineers PLLC, 213 E. Seneca Street, Ithaca, NY 14850; mcp@elwynpalmer.com; [6]Vice President, AMEC Americas, 121 Innovation Drive, Suite 200, Irvine, CA 92617; bruce.corkle@amec.com

ABSTRACT: The City of Los Angeles has depended on imported water since 1913 and devotes substantial resources to maintain the Los Angeles Aqueduct and related infrastructure. The 1906 San Francisco earthquake occurred during aqueduct design, and the San Andreas Fault was soon recognized as a major earthquake hazard that could not be avoided. The aqueduct crosses the fault in the middle of the Elizabeth Tunnel section (8-km- [5-mi-] long, concrete-lined, horseshoe-shaped). The current tunnel capacity is 19.6 m^3/s (310,000 gal/min) or approximately 1.69 billion L/d (446 million gal/d). A major earthquake generated by San Andreas Fault is expected to produce lateral displacement and strong shaking. Displacement of Elizabeth Tunnel at the fault might be 3 m (10 ft) or less over a zone 3 m (10 ft) or more wide. High-density polyethylene (HDPE) pipe in New Zealand proved to be resilient during earthquakes in 2010 and 2011. The City of Los Angeles plans to install an HDPE pipe section across the fault zone to provide a means for some water to pass through the tunnel after the next San Andreas Fault earthquake. The capacity of the tunnel under normal operating conditions will be reduced, but if the HDPE pipe remains open, a 0.91-m- (36-in-) diameter pipe could pass about 18 percent of the current capacity.

The Los Angeles Aqueduct is existing infrastructure upon which the City of Los Angeles depends. Conserving water and maintaining infrastructure to extend life cycles are major parts of the City's sustainability program. The planned modifications are an innovative approach that could improve the likelihood that some of the City's water will cross the San Andreas Fault after the next major earthquake. Two other aqueducts bring water to Southern California (Colorado River Aqueduct and California Aqueduct), both of which cross the San Andreas Fault in canal sections.

© ASCE 2014

INTRODUCTION

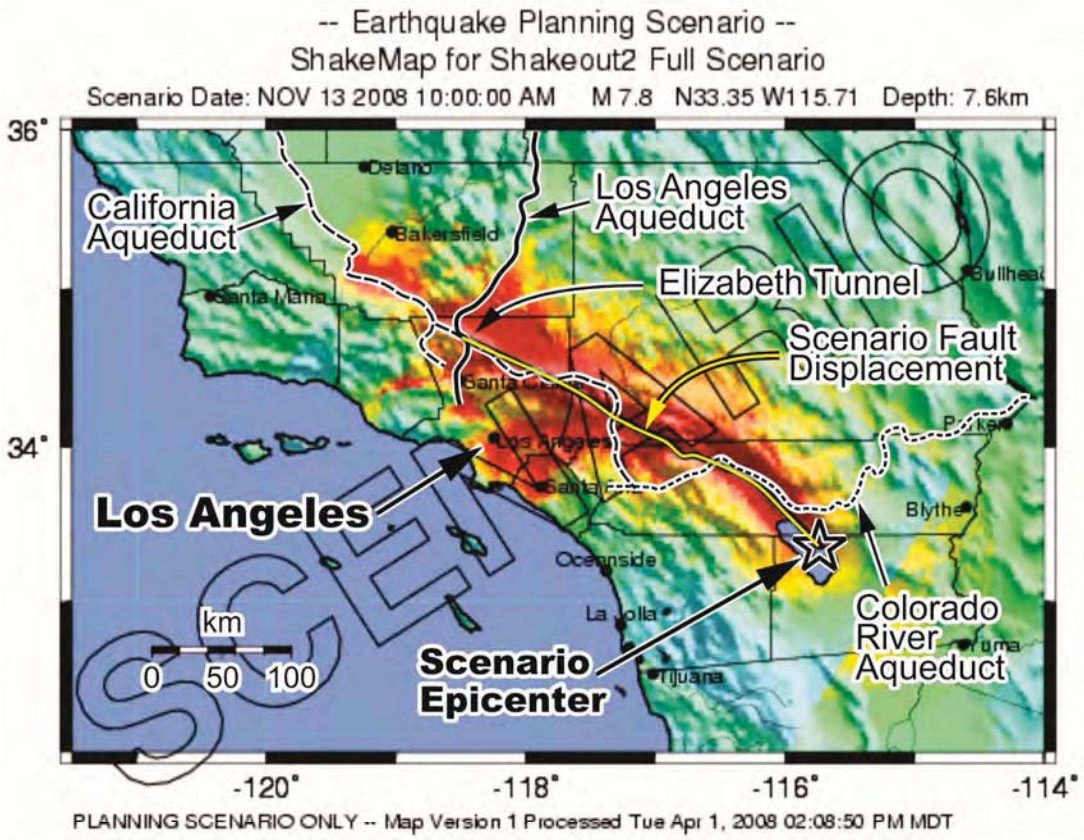
The purpose of this paper is to describe enhancements being considered by the City of Los Angeles Department of Water and Power (LADWP) for delivery of water across the San Andreas Fault following a major earthquake on the fault. The enhancements are not improvements to the tunnel, but rather installation of a resilient pipe that has favorable load-deflection characteristics which is expected to survive some level of fault displacement. The pipe material being considered is high-density polyethylene (HDPE) because of its excellent performance in earthquakes and in laboratory tests of permanent ground deformation (O'Rourke et al., 2008; 2012).

The City of Los Angeles has depended on imported water since 1913 and devotes substantial resources to maintain the Los Angeles Aqueduct and related infrastructure. Design of the aqueduct began before the 1906 San Francisco earthquake; by the time aqueduct construction began, the San Andreas Fault was recognized as a major earthquake hazard that could not be avoided. Immediately following construction of the aqueduct system, its designer called for the City of Los Angeles to make plans for delivering water after it is damaged by the next earthquake. The aqueduct crosses the San Andreas Fault at about the midpoint of the 8-km- (5-mi-) long Elizabeth Tunnel, a concrete-lined, horseshoe-shaped tunnel about 3.3 m (11 ft) high and 2.9 m (9.5 ft) wide. The second Los Angeles Aqueduct was completed in 1970; this aqueduct joins the first Los Angeles Aqueduct at a point very close to the inlet of the Elizabeth Tunnel; therefore, 100 percent of the Los Angeles Aqueduct water crosses the San Andreas Fault in the Elizabeth Tunnel. The current operational capacity of the tunnel is nearly 19.6 m^3/s (310,000 gal/min) or approximately 1.69 billion L/d (446 million gal/d).

A major earthquake generated by the San Andreas Fault is expected to produce up to 6 m (20 ft) of lateral displacement in addition to strong shaking. Depending on where the earthquake epicenter location, displacement of the Elizabeth Tunnel at the San Andreas Fault might be 3 m (10 ft) or less and take place over a zone that is 3 m (10 ft) or more wide (Sutherland et al. 2014). High-density polyethylene (HDPE) pipe proved to be resilient and performed well during earthquakes that generated liquefaction ground failure in 2010 and 2011 in New Zealand. Based on this good performance, the City of Los Angeles is making plans to install a section of HDPE pipe inside the tunnel across the fault zone to provide a means for some water to pass through the tunnel after the next San Andreas Fault earthquake in Southern California. Pipe diameters ranging from iron pipe size (IPS) 30 to 42 (i.e., 30 to 42 inches) are being evaluated. A section of HDPE pipe inside the tunnel will reduce the capacity of the tunnel under normal operating conditions; however, the impact of reduced cross-sectional area and increased hydraulic radius of the tunnel will be relatively minor.

The occurrence of the maximum displacement along the fault at the Elizabeth Tunnel would cut even the most resilient of pipe materials. Therefore, the seismic event being used for planning the water-delivery enhancement is the ShakeOut Scenario earthquake of November 13, 2008 (Jones et al., 2008). This scenario earthquake had a moment magnitude (**M**) of 7.8 with an epicenter located in the Imperial Valley, about 300 km (185 mi) southeast of the Elizabeth Tunnel (Fig. 1).

© ASCE 2014



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

FIG. 1. ShakeMap instrumental intensity of the ShakeOut Scenario Earthquake of November 13, 2008, on the San Andreas Fault in Southern California. Base from USGS website (http://earthquake.usgs.gov/earthquakes/shakemap/2008); aqueduct locations based on Davis and O'Rourke (2011).

The water supply for Southern California is approximately 85 percent imported and nearly 15 percent provided by groundwater pumping with a relatively small amount of water provided by local catchments of direct runoff (Davis and O'Rourke, 2011). In addition to the First and Second Los Angeles Aqueducts, two other aqueducts import water to Southern California. The Colorado River Aqueduct, operated by Metropolitan Water District, and the California Aqueduct, operated by California Department of Water Resources, both cross the San Andreas Fault in canal sections.

The remaining sections of this paper contain descriptions of relevant aspects of the Los Angeles Aqueduct and the Elizabeth Tunnel, the 2008 scenario earthquake, expected earthquake performance of the Elizabeth Tunnel and a section of HDPE pipe placed inside the tunnel, and selected aspects of sustainability.

© ASCE 2014

LOS ANGELES AQUEDUCT AND ELIZABETH TUNNEL

The Los Angeles Aqueduct is 375 km (233 mi) long (City of Los Angeles, 1916), including 98 km (61 mi) of open canal, 157 km (98 mi) of covered conduit, 19 km (12 mi) of siphons, 16 km (10 mi) of power waterways, and 142 lined tunnels with a combined length of 69 km (43 mi). The Los Angeles Aqueduct is entirely gravity flow and includes two hydroelectric power plants south of the Elizabeth Tunnel.

The Elizabeth Tunnel is the northern of a series of tunnels that convey water from the Mojave Desert across the San Gabriel Mountains. It was designed as a pressure tunnel and was part of the aqueduct that could generate electric power. It has a horseshoe cross section about 3.3 m (11 ft) high and 2.9 m (9.5 ft) wide (Fig. 2). Its design discharge was 28.3 m^3/s (1000 ft^3/s; Fig. 2); however, its normal operating capacity in 2013 was 19.5 m^3/s (690 ft^3/s). The tunnel cross section was supported with timber sets and lagging (Figs. 2 and 3) where needed and lined with concrete; steel sets and timber lagging were used in some places.

The Elizabeth Tunnel was driven simultaneously from two headings; the drive from the south began October 5, 1907, whereas the drive from the north began on November 1, 1907. The two drives met on February 28, 1911, with a total length of 8,190 m (26,870 ft). The tunnel excavation was completed in 1,215 days at an average rate of 6.74 m/d (22.1 ft/d). At the time it was completed, the Elizabeth Tunnel was the longest on the Los Angeles Aqueduct and the second longest in the United States; a hard rock tunnel driving record was set with 184 m (604 ft) being driven in a single month. The Los Angeles Aqueduct system went into service on November 5, 1913 (City of Los Angeles, 1916).

2008 SHAKEOUT SCENARIO EARTHQUAKE

The scenario earthquake of November 13, 2008 (Jones et al., 2008) was developed by the US Geological Survey in conjunction with the California Geological Survey for emergency response planning and to allow evaluation of impacts on critical infrastructure that such an earthquake would have (Davis and O'Rourke, 2011). This earthquake emergency response exercise was called the Great Southern California ShakeOut (ShakeOut Scenario). The ShakeOut Scenario was a large-magnitude plausible seismic event, rather than a worst-case scenario; it was a moment magnitude (**M**) 7.8 earthquake on the southern San Andreas Fault with an epicenter on the east shore of the Salton Sea in northern Imperial County (Fig. 1). Surface fault rupture began at the epicenter and progressed northwest a distance of 300 km (185 mi), ending at the town of Lake Hughes. The Elizabeth Tunnel crosses the San Andreas Fault at a point that is on the order of 3 km (2 mi) southeast of Lake Hughes.

The ShakeOut Scenario median and 84th percentile fault displacements at the Elizabeth Tunnel would be 0.45 and 1.65 m (1.5 and 5.4 ft), respectively, as the rupture diminishes to zero (Chen and Peterson, 2011). The most recent San Andreas Fault earthquake in the tunnel region occurred in 1857 with an overall average right-lateral displacement less than 3.5 m (11.5 ft; Zielke et al., 2012). The earthquake catalog since 1913 when the Los Angeles Aqueduct was put into service reveals that the closest earthquake of **M** 5 or greater was approximately 30 km (19 mi) to the

© ASCE 2014

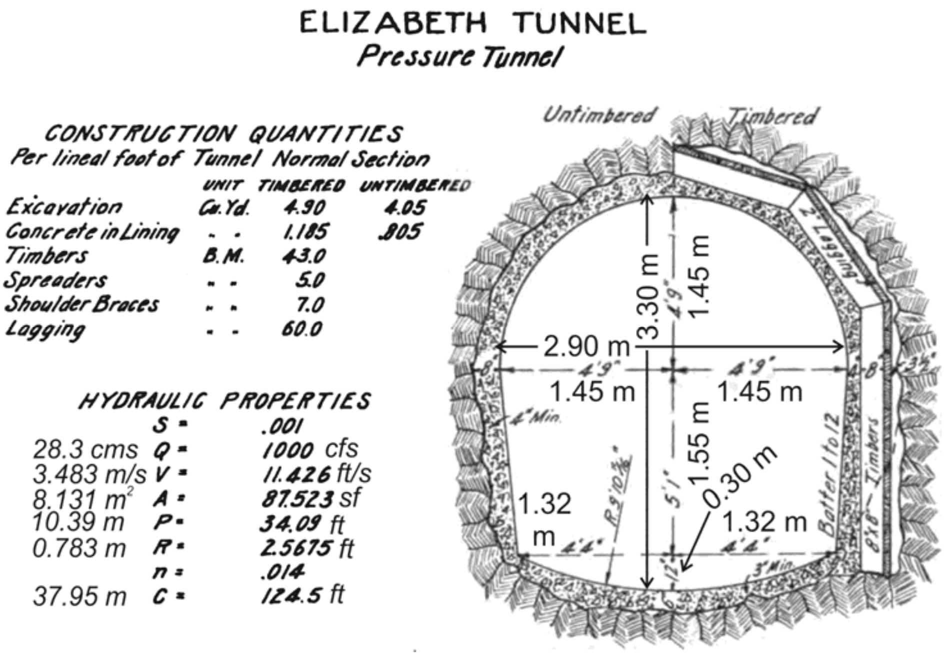


FIG. 2. Design cross section and hydraulic properties of the Elizabeth Tunnel. Modified from City of Los Angeles (1916).

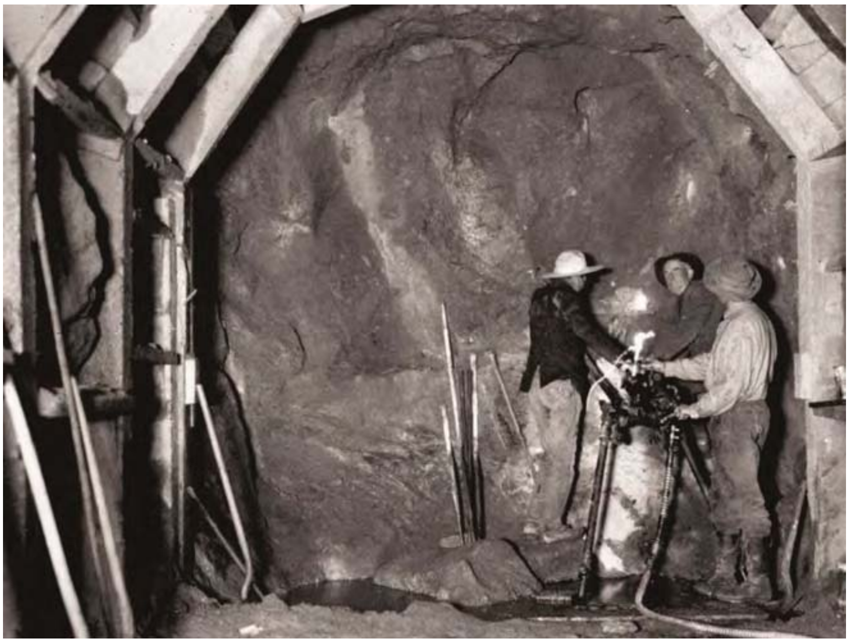


FIG. 3. Elizabeth Tunnel construction in 1908 showing timber sets and lagging. Source: Department of Water and Power archives; used with permission.

southeast (1971 San Fernando earthquake, **M** 6.6). Therefore, the historical seismic record indicates a large displacement on the San Andreas Fault before the tunnel was constructed and no nearby earthquakes of moderate magnitude since the Los Angeles Aqueduct was put into service. Consequently, roof collapse under strong ground motion should be expected because the tunnel has not had a full-scale shaking test.

© ASCE 2014

The Elizabeth Tunnel is expected to be damaged by a fault-displacement event, which is the reason that plans are being made to install a resilient HDPE pipe inside the tunnel. No HDPE pipe would be able to survive a maximum 9-m (30-ft) fault displacement along the San Andreas Fault. Similarly, the ShakeOut Scenario fault displacement at the Elizabeth Tunnel (<1 m [<3 ft]) seemed too small for design considerations. Therefore, we used the **M** 7.8 ShakeOut Scenario earthquake magnitude and estimated the median fault displacement based on Chen and Peterson (2011) for the middle of the fault without considering the end-of-fault decrease:

$$\boldsymbol{D} = \exp(1.7658\,\boldsymbol{M} - 7.8962 + 0.9624\,\boldsymbol{n})$$

where $\boldsymbol{D}$ is displacement in cm, exp(·) is the exponential function of (·), $\boldsymbol{M}$ is moment magnitude, and $\boldsymbol{n}$ is the number of standard deviations ($\ln(1\sigma) = 0.9624$). Thus, the ShakeOut Scenario earthquake would be expected to produce a median slip ($\boldsymbol{n} = 0$) of 356.7 cm (3.6 m, 11.8 ft). The smallest HDPE pipe under consideration is IPS30; therefore, fault displacements were expressed as the number of standard deviations associated with a **M** 7.8 fault displacement that would either completely close the tunnel or encroach on an HDPE pipe in the tunnel (IPS30, 762-mm [30-in.] diameter). Strike-slip displacement thresholds (Fig. 4) represent (1) complete separation of the tunnel ($\boldsymbol{n} = 0$), (2) tunnel closing and crushing the pipe ($\boldsymbol{n} = -1/3$), and (3) tunnel wall encroachment on the pipe ($\boldsymbol{n} = -2/3$).

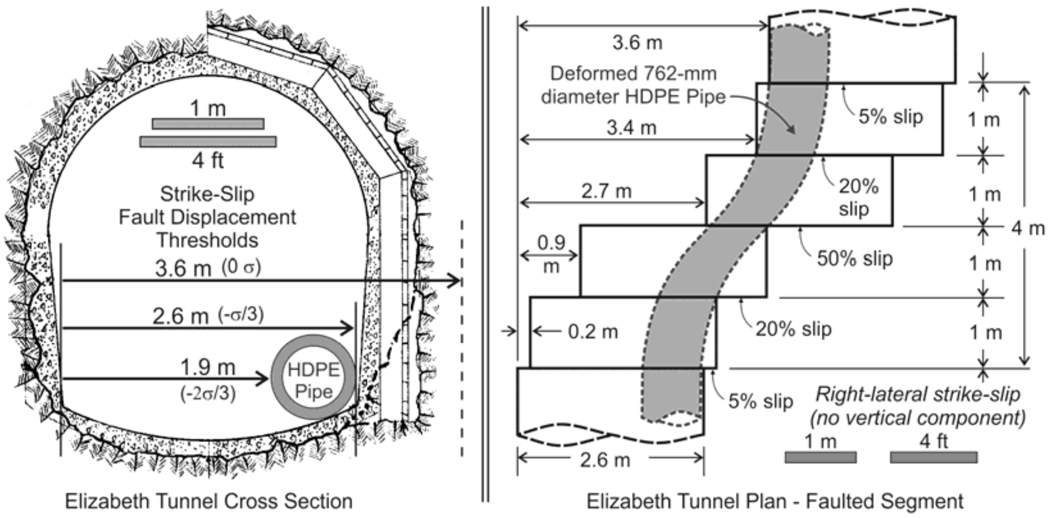


FIG. 4. Elizabeth Tunnel cross section and plan showing fault slip scenario. Left. Cross section; Right. Plan with five fault traces distributed over 4 m length.

EXPECTED PERFORMANCE OF TUNNEL AND PIPE

Fault rupture through the Elizabeth Tunnel is expected to cause so much damage to the tunnel lining and rock in the tunnel walls and roof that the tunnel would be blocked to normal water flow. As-built geologic descriptions from the original tunnel construction are incomplete, but in some places describe poor rock conditions that might be expected to collapse under strong earthquake shaking.

A section of IPS30 HDPE pipe with a wall thickness of 69.3 mm (2.73 in.; DR 11, Grade 4710 HDPE) could accommodate the ShakeOut Scenario median 3.6-m displacement distributed over a horizontal distance of 4 m (13 ft) (Fig. 4) if the pipe were anchored only at one point at least 244 m (800 ft) north of the fault crossing. The boundaries of a state-regulated fault hazard zone (Hart, 1994) are about 244 m away from the fault and are being used as reference positions for the seismic enhancements. If the pipe were constrained by a roof collapse or faulting pattern at the limits of the 4-m wide scenario fault zone, however, then the tensile strength of the HDPE pipe would be exceeded substantially. The estimated tensile stress on the pipe restrained 244 m from the fault would be 269 kPa (39 psi), whereas it would be 848 MPa (123 ksi) if the pipe were fixed at the limits of the fault rupture zone.

A profile of Elizabeth Tunnel compiled by LADWP in 1944 describes rock conditions in some locations where as-built information was available. The rock condition notes range from "massive granite, slight seepage" to "rotten altered granite, mixed with talc". Other rock condition notes indicate "hard granite with mud seams dividing it into big slabs" and "heavy badly fractured, badly caving, heavy flow of water". The worst quality rock in the tunnel documented in notes appears to be located 450 to 1200 m (1500 to 4000 ft) south of the San Andreas Fault; however, the rock condition notes are present in only 28 locations along the entire tunnel. Based on these notes, Sutherland et al. (2014) evaluated two roof collapse scenarios: (1) an intact block dropping directly onto the pipe and (2) disrupted roof collapse.

An intact 66-kN (7.4-ton) block of weathered granitic rock ($2.44 \times 1.83 \times 0.61$ m [$8 \times 6 \times 2$ ft], 24.3 kN/m^3 [155 lb/ft^3] unit weight) was assumed to drop vertically 2.59 m (8.5 ft) onto the pipe. The block was assumed to drop through air instead of water, producing a kinetic energy of 171.5 kJ and an impact stress of 89 kPa (12.9 psi). The rock block impacting IPS30 DR 11 4710 HDPE Pipe (762 mm diameter) resulted in a calculated deflection of 30.5 mm (1.2 in.) or about 4% of the pipe diameter which is less than the 5% deflection considered acceptable for HDPE pipe.

Sutherland et al. (2014) assumed that the tunnel would be blocked over a distance of about 18 m (60 ft) along the crown by a collapse volume of 2523 m^3 (3300 yd^3) which spread out over 79 m (260 ft) of tunnel floor distance. Rock from the disrupted roof collapse was estimated to have a unit weight of about 90% of intact weathered granite (i.e., 21.9 kN/m^3 [139 lb/ft^3]). Impulse loading pressure on the pipe was estimated to be less than the pressure from an intact block impact (82.5 kPa [12 psi]). Therefore, the rock block deflection would govern selection of HDPE pipe.

Based on the fault displacement and the roof collapse considerations, HDPE pipe of thinner wall or larger diameter appeared to be viable for use to enhance the likelihood that water could pass through the Elizabeth Tunnel after the ShakeOut Scenario earthquake. Consideration currently is being given to IPS36 and IPS42 HDPE pipe. HDPE pipe material (polymer 4710) has a specific gravity less than water; hence, its buoyancy must be restrained by anchors. HDPE pipe material also has substantial thermal expansion characteristics. Seasonal water temperature in the tunnel can vary over 23.3°C (42°F). Consequently, the pipe restraints must allow pipe elongation and contraction but control floating. Anchors into the tunnel walls were considered likely to encounter timber sets and lagging with voids behind the lagging (Fig. 4); therefore, anchors will be installed into the tunnel floor only.

© ASCE 2014

SUSTAINABILITY CONSIDERATIONS

The LADWP website (www.ladwp.com, About Us, In Our Community, Going Green) contains a Commitment to Sustainability page which defines Sustainability as "meeting the needs of current generations without impairing the ability of future generations to meet their own needs". It notes that "Sustainability is an important strategy for the long-term health of the people, economy, and environment of California. LADWP's sustainability strategies include the following:

1) Reduce our dependence on fossil-based energy supplies
2) Develop and increase the use of renewable energy resources
3) Implement the city's green building policies at all LADWP facilities
4) Review practices for opportunities to improve overall operational sustainability and streamline with strategic plans
5) Engage and educate our customers to take a more active role in assessing their own energy and water use, and adopting personal sustainability habits
6) Monitor, measure, and continually improve our sustainability practices
7) Develop and increase the use of reclaimed water and preserve local water supply"

Maintaining existing infrastructure to extend its useful life is consistent with principles of sustainability and LADWP's sustainability strategies 1, 2, and 4. The 2008 ShakeOut Scenario earthquake exercise drew attention to the vulnerability of Southern California's water supply. The Los Angeles Aqueduct crosses the San Andreas Fault in the Elizabeth Tunnel, whereas the Colorado River Aqueduct and the California Aqueduct both cross the fault in canal sections. The ShakeOut Scenario event would produce large fault displacements at both canals, whereas, the Los Angeles Aqueduct is near the end of the fault rupture. A tunnel is susceptible to more severe fault-rupture damage than a canal, and certainly damage to a tunnel will be more difficult, costly, and time-consuming to repair than damage to a canal at the ground surface. Conserving water and maintaining infrastructure to extend life cycles are major parts of the City's sustainability program (supporting Strategy 4). The aqueduct water flows through two hydro-power plants downstream of the Elizabeth Tunnel; therefore, loss of water flow because of damage to the tunnel would reduce the production of power from a renewable energy source (challenging Strategy 2 and possibly Strategy 1).

The resilience of HDPE pipe subjected to seismically induced permanent ground deformation has been demonstrated in both actual earthquakes and in large-scale laboratory studies of pipeline behavior subjected to large deformations. The enhancement for delivering water through the Elizabeth Tunnel with a relatively small diameter pipe inside the tunnel will provide some measure of reliability for water flow while limiting the negative impact on normal operational capacity of the tunnel. The seismic enhancement concept is to place an open section of HDPE pipe in the tunnel during a scheduled maintenance period when the tunnel can be drained, anchor the pipe at the upstream end to prevent it from being transported down the tunnel during normal operation, and extend the pipe during subsequent normal maintenance periods. The flow capacity of the tunnel with a 5-km-(16,400-ft-) long

© ASCE 2014

section of IPS36 DR 15.5 HDPE pipe installed in it would exceed the current normal operating flow of 19.54 m^3/s (690 ft^3/s); therefore, the presence of the HDPE pipe inside the tunnel would have negligible effect on operating flow.

Following a seismic event that blocks the tunnel, water will flow only through the HDPE pipe if the pipe survives the fault rupture and if a roof collapse does not block the tunnel at a location where the pipe has not been installed. Flow in the surviving HDPE pipe inside the blocked tunnel would enter the upstream end of the pipe under pressure of water in the blocked tunnel. Assuming that the tunnel is blocked but the pipe is unobstructed by the seismic event, flow would be a function of the length of length of the pipe section because of friction losses. Fault rupture is the primary reason for installing a section of HDPE pipe in the tunnel; documented poor rock quality downstream of the fault hazard zone is a secondary reason for extending the length of HDPE pipe. Water delivery through an HDPE pipe in the collapsed tunnel is a function of the pipe diameter, wall thickness, and length (Tab. 1).

Tab. 1. Summary of water flow by gravity in HDPE pipe inside blocked Elizabeth Tunnel. IPS denotes Iron Pipe Size (inches), DR denotes diameter ratio to wall thickness, normal operational discharge is 19.54 m^3/s.

IPS	DR	Hazard, Length (m) [ft]	Discharge (m^3/s) [gal/min]	Discharge ÷ 19.54 m^3/s (%)
30	11	Fault, 488 [1600]	2.30 [36,400]	11.8
36	15.5	Fault, 488 [1600]	4.26 [67,568]	21.8
36	15.5	Fault & roof collapse, 1585 [5200]	2.43 [38,542]	12.4
36	17	Fault & roof collapse, 1585 [5200]	2.52 [39,930]	12.9
36	17	Extend to inlet, 4957 [16,264]	1.44 [22,869]	7.4
42	17	Extend to inlet, 4957 [16,264]	2.16 [34,176]	11.0
36	17	Pumped, 4957 [16,264]	2.66 [42,212]	13.6
42	17	Pumped, 4957 [16,264]	4.00 [63,329]	20.4

One possible option for increasing emergency discharge through the HDPE pipe would be to use pumps to pressurize water at the upstream end of the pipe. This possibility would be available only for the options that extend the pipe from the poor rock condition downstream of the fault zone to the upstream end of the tunnel, a distance of 4957 m (16,264 ft) (last two rows in Tab. 1). Larger pipe sizes, of course, can deliver more water than smaller pipe sizes. Evaluations are under way for the IPS 36 and 42 pipes from a constructability perspective. Sections of pipe will have to be moved inside the tunnel with small equipment that has limited pulling capacity. Sections of HDPE pipe can be welded for fused together in a staging area outside the tunnel. The four sizes of HDPE pipe listed in Tab. 1 have the following weights:

IPS30 DR11 1.494 kN/m (102.4 lb/ft), IPS36 DR15.5 1.574 kN/m (107.9 lb/ft),
IPS36 DR17 1.445 kN/m (99.0 lb/ft), IPS42 DR17 1.966 kN/m (134.7 lb/ft).

The of tractors that have been used for maintenance activities inside the tunnel have a pulling capacity of about 6.23 kN (1400 lb) with all wheels in residual water on the tunnel floor. With five tractors pulling in tandem, sections of the four pipe sizes listed above that could be skidded would be limited to lengths of 20.8 m (68.2 ft), 19.8 m

© ASCE 2014

(65.0 ft), 21.6 m (70.9 ft), and 15.8 m (51.8 ft), respectively. Shorter sections prepared outside the tunnel require more welding of fusing inside the tunnel. Equipment for welding IPS42 HDPE pipe inside the Elizabeth Tunnel may not be available. Furthermore, the sequencing requires placing pipe across the fault zone first; therefore, some pipe sections would have to be skidded past in place pipe for the downstream poor rock condition. Optimization studies integrating constructability and economics have not been completed, but the preferred size may be IPS36 DR17. If the 1585-m- (5200-ft-) long fault and roof collapse zone were mitigated in two tunnel maintenance shutdown periods each with 13 days of pipe placement, then 61 m/d (200 ft/d) of pipe would have to be placed, welded or fused, and anchored.

Pumping options (last four rows in Tab. 1) reveal that pumping could deliver 84 percent more water through IPS36 pipe and 86 percent more water through IPS42 pipe than gravity-flow options. These options would require three 746 kW (1000 HP) pumps for IPS36 DR17 pipe or three 1119 kW (1500 HP) pumps for IPS42 DR17 pipe. Post-earthquake conditions probably will result in power outages along the fault rupture that could last as much as 14 days; therefore, the planning considered on-site fuel storage to run the pumps for 14 days. About 184,560 L (48,755 gal) of fuel would need to be stored for three 746-kW pumps, whereas 280,130 L (74,795 gal) would need to be stored for three 1119-kW pumps.

Consideration also was given to using steel pipe between the upstream end of the HDPE pipe in the fault hazard zone and the tunnel inlet. The benefit of the steel pipe would be higher pressure at the tunnel inlet because of pressure limits of HDPE pipe and typically lower cost of steel pipe compared to HDPE pipe (stainless steel probably would be required to limit corrosion concerns). Nominal pipe size (NPS) 36 with 0.250 inch wall thickness (0.914 m diameter with 6.35 mm wall thickness) made of stainless steel would weight about 1.42 kN/m (97.3 lb/ft), whereas NPS42 with 0.250 wall thickness (1.067 m diameter with 6.35 mm wall thickness) made of stainless steel would weigh about 1.66 kN/m (113.8 lb/ft). The weights are comparable to HDPE pipe; however, skidding HDPE is common practice and does not degrade the material, whereas skidding stainless steel pipe typically is avoided.

The pumped options (last two rows in Tab. 1) with steel pipe upstream of the fault hazard zone would produce discharges of 4.70 and 6.96 m^3/s (74,426 and 110,358 gal/min), respectively, which is equivalent to 24.0 and 35.6 percent of 19.54 m^3/s normal operational discharge. Delivery of these discharges would require four and six 2985 kW (4000 HP) pumps with fuel storage of 961,900 and 1,279,100 L (254,100 and 337,900 gal), respectively.

The Elizabeth Tunnel was supported with timber sets and lagging at the time of construction and then lined with concrete. Voids are likely to be present between the lagging and the tunnel wall. Therefore, pipe anchorage will be attached to the tunnel floor to avoid complications of the timber sets, voids, and loose rock fragments that may exist behind the concrete lining on the tunnel wall. Stainless steel bars will be used. HDPE pipe sections can be installed and anchored to the tunnel floor incrementally during annual periods of aqueduct system shutdown. The pipe initially will be placed across the fault zone, and then extended downstream in subsequent years through the poor rock quality zone, and ultimately to the upstream end where a pump could be connected for pressure flow.

© ASCE 2014

The planned seismic enhancements are limited in scope and would not constitute a comprehensive seismic evaluation or a seismic upgrade to the Elizabeth Tunnel. The sole intent of the planned seismic enhancements is to improve the likelihood that at least some water is delivered to the nearly 4 million people in the City of Los Angeles who receive water passing across the San Andreas Fault in the Elizabeth Tunnel. The planned seismic enhancements would have minor impact on delivery of water through the tunnel during normal operations, could be constructed in phases that coincided with maintenance shutdown periods, and have a relatively modest cost.

ACKNOWLEDGMENTS

The director of this evaluation was Craig A. Davis, Ph.D., P.E., G.E., Geotechnical Engineering Manager, Los Angeles Department of Water and Power. Christopher Heron, C.E.G., Engineering Geologist, Los Angeles Department of Water and Power, participated in geologic reconnaissance and provided valuable discussion. Ian Maclean, David Wilson, Peter Yuan, and Ed Trasoras, AMEC Americas, performed in-tunnel anchor testing. Thomas D. O’Rourke, Ph.D., Cornell University, and Lloyd S. Cluff, C.E.G., Pacific Gas & Electric, served on LADWP’s advisory board.

REFERENCES

Chen, R., and Peterson, M.D. (2011). “Probabilistic fault displacement hazards for the southern San Andreas Fault using scenarios and empirical slips.” *Earthquake Spectra*. 27 (2): 293–313.

City of Los Angeles. (1916). *Complete report on construction of the Los Angeles Aqueduct*. Department of Public Service. http://books.google.com/books?id=fC4SAAAAIAAJ&ie=ISO-8859-1 (June 2013).

Davis, C. and O’Rourke, T. (2011). “ShakeOut scenario: Water system impacts from a M_w 7.8 San Andreas earthquake.” *Earthquake Spectra*. 27 (2): 459-476.

Hart, E.W. (1994). “Fault rupture hazard zones in California: Alquist-Priolo Earthquake Fault Zoning Act with index to earthquake fault zones maps.” California Dept. of Conservation, Div. of Mines and Geology, Sacramento.

Jacobs, J.D. (1975). “Some tunnel failures and what they have taught.” *Hazards in tunneling and on falsework*. Institution of Civil Engineers, London. 37-46.

Jones, L.M., Bernknopf, R., Cox, D., Goltz, J., Hudnut, K., Mileti, D., Perry, S., Ponti, D., Porter, K., Reichle, M., Seligson, H., Shoaf, K., Treiman, J., and Wein, A. (2008). *The ShakeOut Scenario*. U.S. Geological Survey Open-File Report 2008-1150 and California Geological Survey Preliminary Report 25, http://pubs.usgs.gov/of/2008/1150 (June 2013).

O'Rourke, T.D., Jezerski, N.A., Olson, T., Bonneau, A.L., Palmer, M.C., Stewart, H.E., O'Rourke, M.J., Abdoun, T. (2008). "Geotechnics of Pipeline System Response to Earthquakes." *Proceedings of Geotechnical Earthquake Engineering and Soil Dynamics IV*. Zeng, D., Manzari, M.T., and Hiltunen, D.R. (eds). ASCE Geotechnical Special Publication GSP181. 1-38.

O’Rourke, T.D., Jeon, S-S., Toprak, S., Cubrinovski, M., and Jung, J.K. (2012). Underground lifeline system performance during the Canterbury earthquake

© ASCE 2014

sequence. Paper presented at *15th World Conference on Earthquake Engineering*, Lisboa. http://www.nees.cornell.edu/upload/15WCEE-Invited-Paper-O-Rourke-et-al.pdf (June 2013).

Sutherland, M., Keaton, J.R., Heron, C., and Kuganenthira, N. (2014). "Seismic Enhancements for Delivering Water to the City of Los Angeles across the San Andreas Fault in the Elizabeth Tunnel." *Proceedings of the 2014 Geo-Congress*. Abu-Farsakh, M., Yu, X., and Hoyos, L.R. (eds). ASCE Geotechnical Special Publication GSP234. 3779-3788.

Terzaghi, K. (1946). "Rock Defects and Loads on Tunnel Support." *Rock Tunneling with Steel Supports*. Proctor, R.V., and White, T. (eds). Commercial Shearing Co., Youngstown, Ohio, USA. 15–99.

Zielke, O., Arrowsmith, J.R., Grant Ludwig, L., and Akciz, S.O. (2012). "High-resolution topography-derived offsets along the 1857 Fort Tejon earthquake rupture trace, San Andreas Fault." Bull. Seismo. Soc. Am. 102 (3): 1135–1154.

© ASCE 2014

Design, Creation and Implementation of Technology for Sustainable Nuclear Remediation Projects

S.D. Rima[1]

[1]AMEC Environment & Infrastructure, Radiological Services and Engineering Department, 2275 Logos Court, Suite A, Grand Junction, CO 81505; PH (970) 208-8396; FAX (970) 256-7356; email: steve.rima@amec.com

Abstract

Billions of dollars are spent worldwide every year on nuclear remediation projects. Most of this work is done now as it was done decades ago, and is very labor and resource intensive. AMEC has developed technology that has been deployed on projects across the U.S, and in Canada, Japan and the UK, that makes such projects shorter in duration and more sustainable through reductions in waste volume requiring permanent disposal and through minimization of resources to complete such projects. Benefits to local communities and taxpayers have included return of land to beneficial public use quicker and at lower cost than traditional methods; reduction of impacts from large workforces and heavy equipment; reduction in greenhouse gas emissions from shorter duration projects using less fossil fuels; and reduction in the volumes of materials that are otherwise needlessly diverted to landfills for disposal as radioactive waste. Information is presented on development of sustainable approaches and solutions to such projects, as well as a case study of where it has been successfully used.

Introduction

Various activities and industries using radioactive materials can result in the release of radioactive material and contamination of the environment. Some examples include mining and milling of uranium and other ore bodies with naturally occurring radioactive material (NORM), oil and gas exploration and extraction, nuclear power, nuclear weapons, some metal alloying processes, production and use of medical radioisotopes, and others. A cogent case can be made that nuclear power is a green technology with regard to carbon emissions, however, unlike the use of fossil fuels for power generation, radioactive contamination of the environment from these activities can pose a hazard to humans and the environment, and is very costly to remediate and dispose of the resulting waste.

Radioactive contamination of the environment can result from the spread of materials via dumping, airborne dispersion, or waterborne materials. In most cases the result is a large volume of potentially contaminated soil in which the radioactive material is heterogeneously incorporated. This results in one of two approaches to remediation; gross overexcavation and disposal of large quantities of soil as Low Level Radioactive Waste (LLRW), or attempts at "pinpoint" or "surgical" excavation that result in schedule delays and cost overruns. Neither of these approaches is desirable

© ASCE 2014

or cost effective, but are the primary approaches that have been in use for several decades.

A technology that can separate contaminated soil and debris from clean, in a real time, fast and cost effective manner has been developed by AMEC and employed at projects in several countries; the result is quicker, less costly, more precise and greener remediation projects.

Discussion

A typical radioactive remediation project involves a higher number of workers than projects without radioactive materials, heavy machinery, and transportation of the waste across vast distances for disposal. Due to stringent environmental and worker protection requirements for managing radioactive material, the overall efficiency of the workforce is lower than similar projects without radioactive materials. The majority of LLRW disposal in the U.S. is in the western part of the country while many of the remediation projects are not in close proximity, which requires transportation by truck or rail across long distances, with the attendant heavy use of fossil fuel. In addition to being resource-intensive, these projects are very expensive for the responsible parties. The transportation and disposal (T&D) cost is very high, particularly for disposal, of LLRW. LLRW T&D can exceed 80% of the total cost at these types of projects, which can be tens to hundreds of acres in size and involved hundreds to thousands of tons of material.

The typical method of remediating radioactive contamination in soil has been to "peel the onion" or remove thin, typically 6-12 inch thick, lifts followed by additional characterization surveys with portable radiation detection instruments and/or sampling and lab analyses. This is then carried out in an iterative process until no remaining contamination is found through surveys or sampling. This is time consuming, uses extensive amounts of fuel for heavy equipment, and usually results in transporting and disposing of clean soil mixed with radioactive soil as there has not been a real-time, cost effective method to adequately distinguish or separate clean from contaminated materials in the field until recently.

AMEC has developed an automated system, called Orion *ScanSort*^{SM}, which uses state-of-the-science methodology, to separate radioactively contaminated material from clean material in the field to assist clients in reducing their remediation liabilities and associated costs and leading to greener remediation projects that use fewer human and other resources. The system employs large, very sensitive radiation detectors on conveyors, using software developed by AMEC, to automatically process, assay and separate contaminated from clean materials at up to 200 tons per hour. The system uses gamma spectroscopy instead of traditional gross gamma methodology, with results traceable to the National Institute of Standards and Technology (NIST). This brings what has traditionally been an expensive and time-consuming lab analysis into the field in real time.

© ASCE 2014

Case Study

In September 1956 ground was broken to build the Plum Brook Reactor Facility near Sandusky, OH. The facility was built primarily to conduct research into nuclear propulsion for space travel. It operated for 11 years until 1973, when the federal government canceled the research program and shut down the reactor for good. The reactor and ancillary facilities remained shut down and monitored until decommissioning began in earnest in 1998.

Beginning in 1973, a number of cost estimates to decommission the reactor and restore the site were developed, with estimates ranging from$1.2 million to $160 million. The final disposition of the site was described in the decommissioning plan, where a plan to decommission and remove the reactor and facilities and clean the 117 acre site to a state where it would be safe for a family to live and grow crops on.

While cost estimates for soil remediation varied, the generally accepted estimate for this phase of the project, inclusive of field work and LLRW packaging, transport and disposal, was $60 million. The majority of this cost was for LLRW transport and disposal.

In 2009 AMEC was subcontracted to supply its Orion *ScanSort*^{SM} system to the Plum Brook Decommissioning Project to segregate soil contaminated with Cs-137 from clean soil. Cs-137, a common radioactive isotope produced in nuclear reactors, had been released to the environment through discharges of contaminated water. Cs-137 has a radioactive half life of approximately 30 years, meaning half will have decayed away in that time and all will have decayed away in approximately 200 years. As a new and relatively unproven technology, regulatory agencies such as the Nuclear Regulatory Commission (NRC) and the Ohio Environmental Protection Agency (Ohio EPA) requested objective evidence that the system would perform as designed and that the clean soil from the system did, in fact, meet the Cs-137 release concentration limit agreed on between NASA and the regulatory agencies. This was accomplished relatively quickly through a demonstration of the technology at the Plum Brook site.

The *ScanSort*^{SM} system is depicted in Figure 1. It consists of a Survey Conveyor on which the soil moves under one or more Detector Assemblies, after which it is discharged onto the Reversing Conveyor, which directs the soil into either clean or contaminated stockpiles via Stacking Conveyors, based on assay from the detectors. The entire system is controlled by local computers, which calculated the concentration of Cs-137, monitored the density of the soil on the Survey Conveyor, controlled the speed of the Survey Conveyor and controlled the direction of the Reversing Conveyor.

© ASCE 2014

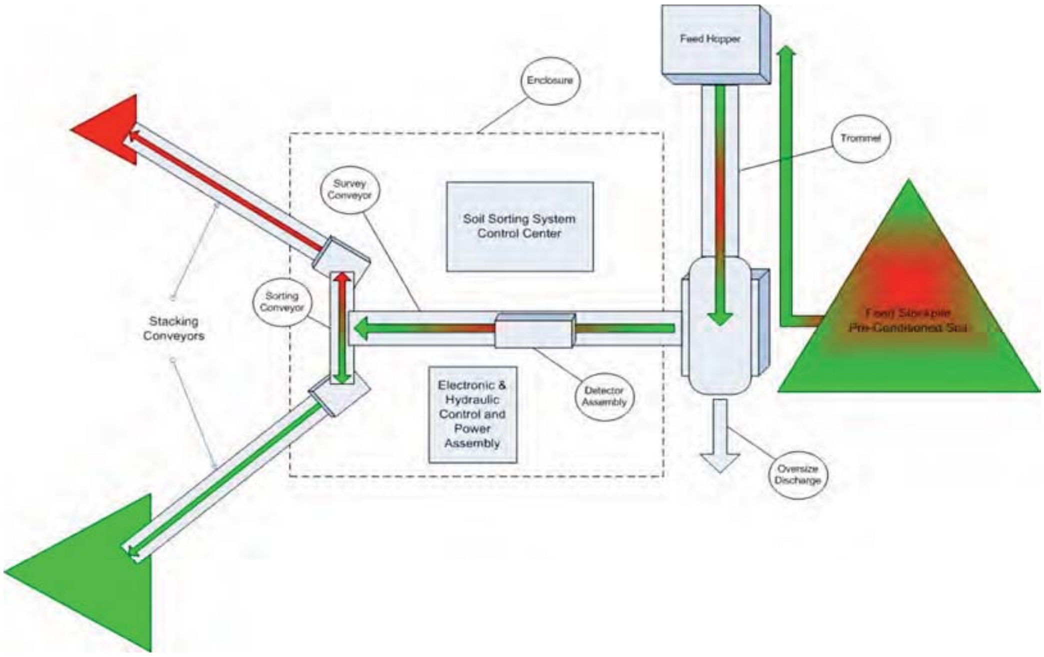


Figure 1
AMEC *ScanSort*^{SM} System Diagram

During its deployment at the NASA Plum Brook project, the *ScanSort*^{SM} system assayed and processed approximately 105,000 tons of soil that had been excavated from various locations that were potentially impacted with Cs-137 contamination. Excavation locations included the Hot Retention Basin shield, Emergency Retention Basin dike, Pentolite Ditch, and other areas. The *ScanSort*^{SM} system deployed to the project was designed to process and segregate at a maximum rate of 1,000 tons per day. AMEC was able to increase that rate to 1,400 tons per day, which significantly reduced the time needed to process the soil, resulting in further cost savings and less fuel used in the equipment used to excavate, move and process the soil. Early estimates were that in excess of 50% of that volume would be found to be contaminated with Cs-137, requiring transport and disposal as LLRW.

On completion of the project it was found that less than 2% of the soil was contaminated with Cs-137 above the acceptable concentration. This resulted in an overall cost reduction of nearly 50% from the estimated $60 million cost. The cost reduction was primarily in two areas; reduced LLRW T&D and decreased labor and equipment costs from the 18 month reduction in the project's scheduled duration.

Figure 2 shows the *ScanSort*^{SM} system during operation at the NASA Plum Brook Project. The dramatic reduction in LLRW volume is evident in the photo. The clean soil was used as backfill on various areas of the site, further reducing costs that would have resulted from importing fill from off site.

© ASCE 2014

Figure 2
AMEC *ScanSort*^{SM} System at NASA Plum Brook Project

Summary

Arguments can be made about how green or sustainable nuclear power and other nuclear-related technologies are; that is not the intent of this paper. Decommissioning and remediation of past nuclear research and production sites is known to be very costly, in large part due to the very high cost of transporting and disposing of Low Level Radioactive Waste and the time consuming remediation process. The processes that resulted in contamination of soil typically leave a heterogeneous mix of contaminated and clean soil comingled *in situ*. Past soil remediation methods have not typically attempted to address the heterogeneity and have resulted in project delays and very large volumes of LLRW, knowing that some fraction of the soil being transported for permanent disposal is in fact clean.

Technology can be used, and has been proven by AMEC at the NASA Plum Brook Reactor Project, as well as at other projects in the United States, Canada and Japan, to reduce both project schedule and LLRW volume, resulting in a greener and more cost effective remediation while still protecting the public and the environment.

References

Bowles, M.D. (2006). "Science in Flux: NASA's Nuclear Program and Plum Brook Station 1955-2005." NASA History Division, Washington, DC.

Bowles, M.D., and Arrighi, R.S. (2004). "NASA's Nuclear Frontier, The Plum Brook Reactor Facility." NASA History Division, Washington, DC.

© ASCE 2014

Sustainable Innovation for Private and Public Sector Infrastructure: Next Generation Challenges for Engineering Education

Terry F. Yosie

President & CEO, World Environment Center, 734 15th Street, NW, Suite 720, Washington, D.C. 20005; PH (202) 312-1210; FAX: (202) 637-2411; email: tyosie@wec.org

ABSTRACT

Emerging concepts and innovations in the design and operation of private and public infrastructures are transforming the application of sustainability thinking within the engineering profession. These changes result from global megatrends such as climate change; water resource availability; population growth and mega-urbanization; a dramatic expansion in the size of the global middle class; technological innovations such as widespread digitization and emergence of new information technology capabilities and services; and new collaboration strategies. The paper presents several mini-case studies that illustrate the new challenges to engineering education in private and public infrastructure and identifies emerging strategies for collaboration involving business, academia and other stakeholders to prepare the next generation of engineering leaders to implement sustainability.

Challenges and Transitions

Several major environmental, economic and social trends are transforming the application of sustainability thinking within the engineering profession. As noted by Hawkins, Patterson, Mogge and Yosie, they include: 1) the growing demand within the private sector and other employers for sustainability-related knowledge, skills and abilities to respond to major global trends such as intensified patterns of urbanization, the expanding middle class in developing nations, challenges in providing sufficient quantities of food and water supplies, and accelerating climate change; 2) an increasing awareness and understanding of sustainability challenges among engineering students coupled with their greater advocacy for sustainability content in their course work; and 3) a growing core body of knowledge that integrates the fundamentals of business and public sector management with sustainability principles and metrics that are being developed by the public and private sectors, academia and non-governmental organizations (Hawkins et al, 2013).

Consideration of sustainability issues is fully compatible with the existing engineering curricula (through instruction in mass and energy balances, for example) and, in a growing number of universities, it is built into a variety of course syllabi. Sustainability also extends the boundaries of such instruction in several ways. These include: transitioning the curricula from teaching molecular and process factors to including a product and bio-systems level scale; designing manufacturing facilities to both optimize efficiencies in natural resource inputs, while also transitioning to a concept of "net zero consumption" of natural resources; and integrating tools for sustainability assessment, such as life cycle analysis, to consider a total systems understanding of the impacts of a range of engineering design and operations choices.

Advancing Infrastructure Resilience

The concept of resilience has emerged as a key design criterion in infrastructure planning and management. As it relates to private and public sector infrastructure, the resilience concept contains three dimensions: 1) greater reliability of performance; 2) reduced impacts from failure; and 3) increased adaptability and "bounce back" from disruptive events. Traditionally, resilience was viewed in a context of managing for earthquake-related risks or other scenarios that were anticipated as high risk-low probability events (e.g., 100-year floods) (Ascher, 2013).

Several developments have begun to transform engineering professionals' understanding of the resilience concept, including:

- A growing recognition of other risk factors to infrastructure that stem from sea-level rise, storm surges, droughts and other factors related to climate change. These risks include disruption of electricity service and public and private transportation systems, and supply chain interruptions that prevent the timely delivery of goods and services to business, hospitals, or retail outlets, to name a few.
- The increasing interdependencies—and, thus, vulnerabilities—of different sets of infrastructures such as power generation, water supply, transportation and communications systems.
- Expanded options to decentralize infrastructure to local solutions rather than continue with centralized approaches to infrastructure management—such as the ability to maintain on-site or localized co-generation capacity when the electricity grid is disabled.

As these challenges gain greater definition and specificity in both individual locations as well as regional and national contexts, there are corresponding opportunities for innovation from engineering professionals. Several case studies can illustrate innovations already underway.

Public Sector Innovation in Infrastructure Planning

Major urban areas in the United States and other nations are expanding their planning efforts to make public infrastructure more resilient in the face of documented evidence, as well as future projections, of higher average temperatures, increasing precipitation, sea level rise, or rainfall

© ASCE 2014

and snowpack declines and extended drought conditions. This examination of resiliency is directly related to the fact that so much current infrastructure lies in projected impact zones.

New York's PlaNYC: One of the most comprehensive urban sustainability initiatives has been developed in New York City. Originally published in October 2007, PlaNYC received added impetus, definition and scope in the aftermath of Hurricane Sandy in October 2012. As presently designed, PlaNYC represents a comprehensive rethinking of managing housing and neighborhoods, water supply and waterways, energy sourcing and distribution, wastewater management and economic development. PlaNYC currently involves the participation of 25 city agencies and multiple stakeholders from academia, business, community, environmental and other organizations.

This collaboration has committed to implementing a number of specific goals for each major PlaNYC element, including the application of 5 million square feet of reflective rooftops and other energy efficiency measures; upgrading building codes (e.g., installing flood-proof equipment and elevating critical energy and wastewater treatment equipment to higher elevations-even within existing buildings); planting 850,000 trees; reducing carbon emissions by 19% since 2005 as part of an overall commitment to achieve a 30% reduction by 2030; investing in natural systems; upgrades to wastewater treatment facilities to protect against storm surges; redesign of storm water drainage infrastructure; and restoring coastal ecosystems (PlaNYC, 2014).

To guide city officials and their stakeholders in understanding infrastructure vulnerability to climate change impacts, the city utilizes a climate change advisory process consisting of leading scientists and engineers that evaluate current and longer-term climate scenarios through the 2050s for average temperature changes, sea level rise and other variables.

San Francisco Bay region: Infrastructures of other urban areas are similarly threatened by climate change and other risk factors. In addition to its on-going concerns about earthquake damage, the San Francisco Bay region is at risk from sea level rise ranging from an estimate of 16 to 55 inches by 2100 even while the region expects to experience continued population growth. To extend this analysis to a more granular level, significant portions of the rail lines, stations and other infrastructure within the Bay Area Transit System (BART) are at varying degrees of risk from sea level rise. An Alameda County Vulnerability Assessment continues to examine options for making BART and other transportation assets, habitats, and land use more resilient with significant investments in infrastructure being planned.

Within the City of San Francisco, a set of sewer system improvement goals seeks to balance green and grey infrastructure to address the following challenges: an aging collection system, excess storm water, seismic activities, sea level rise and optimization of operations. Specific

© ASCE 2014

improvement goals call for a compliant, reliable and flexible sewer system that can also respond to catastrophic events; integrate green and grey infrastructure to manage storm water; modify the resiliency of the sewer system to adapt to climate change (including sea level rise); achieve economic and environmental sustainability; and maintain ratepayer affordability.

City officials are applying a Triple Bottom Line (TBL) assessment model to identify planning options and to optimize their decision making. The TBL evaluation criteria include capital, operational and other costs, environmental factors (e.g., climate, habitat, water use, water quality, air quality, natural resource inputs) and social factors (e.g., ratepayer affordability, recreation and open space, employment, cultural resources, construction impacts, the pedestrian environment, and noise and odor). The TBL model works as a screening process but also embodies a ratings system of potential responses across financial, environmental and social variables. A TBL Community Values Survey is used as an overlay to inform the TBL model (San Francisco PUC, 2012).

Private Sector Innovation in Infrastructure Planning

There is an expanding commitment to examining business risks in the private sector, and many of these assessments focus on infrastructure. Three examples highlight the current state of thinking about infrastructure risk and resilience.

Walt Disney's Climate Program: As part of its global environmental stewardship and citizenship program, Disney has committed to two major climate-related goals. These include: 1) achieving net zero direct greenhouse gas emissions; and 2) reducing indirect greenhouse gas emissions from electricity consumption. For each of these goals, the company has set near-term targets that it periodically updates. Implementing its climate program has a number of direct implications for Disney's infrastructure and investments. They include:

- Analyzing sea level rise and storm frequency data before signing theme park construction contracts.
- Applying a pro-rated internal carbon tax across its business units to reduce carbon dioxide emissions from key infrastructure (e.g., cruise ships, bus fleets, theme parks). The fewer emissions from a business unit, the lower is its carbon tax.
- Investing in energy efficiency, renewable energy and biofuels. This also includes application of low resistance coatings for the hulls of cruise ships as well as alternative docking procedures to minimize energy consumption and emissions.
- Investing in carbon offsets through global forestry conservation (Rauhe, 2013).

© ASCE 2014

Ingersoll Rand's resilient buildings program. Through its Trane brand, the company provides a broad range of energy efficient residential and commercial heating, ventilation and air conditioning (HVAC) systems and services.

To improve the resiliency of buildings infrastructure Trane is implementing a High Performance Buildings initiative. These are buildings that are designed, built and operated to improve occupant productivity, provide a safer, healthier and more comfortable environment, minimize unscheduled downtime, and maintain building performance within acceptance tolerances over its lifespan. In areas frequented by hurricane or tornado activities, there is often significant disruption to building performance that is difficult to quantify in advance. Rather than close these buildings, an expanding option for resilience is to provide temporary power through on-site mobile generators, install temporary cooling and dehumidifying services and maintain comfortable working or living conditions while normal building services are restored.

Increasingly high temperatures also impact building performance. In Northern Virginia, for example, hospitals lose air conditioning when the heat index exceeds 105° F; frequently, no cooling contingency plan is in place, and disruptions to hospital operations can occur. As temperatures increase in a variety of locations across the globe, greater contingency planning will be needed to avoid disruption to important business and civic functions that rely upon effective building performance (Taival, 2013).

Planning resilient infrastructure in oil and gas operations: The oil and gas industry operates across a wide range of weather, geographic and geological conditions that are increasingly experiencing business risks from climate impacts. These risks lead to a number of consequences, including:

- Shortened work days and increased employee hardships in hot climates.
- Expanded disease distribution over a wider area of operations.
- Delays in tundra travel and shorter ice road seasons that result in delays in equipment and staff delivery.
- Increased maintenance due to infrastructure subsidence from ice/soil thaw and frost jacking.
- Insufficient or low quality water supplies.
- Flood impacts on local assets.
- More frequent power outages, work stoppages and production disruptions due to storm frequencies and strength of wind speed.

While climate change may also provide a benefit by extending the summer work season in temperate climate zones and open new shipping routes in polar regions, the oil and gas industry

© ASCE 2014

faces numerous and expensive resilience challenges to its infrastructure around the world that require continued assessment and response (Yosie 2012).

Preparing Engineers to Implement Sustainability Through Enhanced Collaboration

No single institution—public or private—has the ability to resolve these and other major challenges. A growing number of corporations, government agencies, non-governmental organizations and universities recognize their interdependencies in attaining their individual objectives. Global companies, for example, are engaged in a major competition for access to talent. The outcome of this competition will not only shape whether they survive in the future, it is critically linked to the core skill sets that are redefining expectations for leadership and technical competency in their business sectors.

Leading institutions such as AECOM, Boeing, Carnegie Mellon University, CH2M Hill, Dow Chemical, ExxonMobil, IBM, Ingersoll Rand, SC Johnson, Stanford University, University of Michigan, and the University of Texas at Austin are responding to these challenges by collaborating to achieve three major objectives:

- Accelerating the transfer of knowledge from the private sector into the classroom.
- Providing students with real-time opportunities to work with companies during their graduate careers to deepen their knowledge of business processes.
- Enabling companies to identify talent at an early stage to fill their pipeline of future employees.

Such collaboration involves the participation of multiple institutions through a common network that aims to dramatically scale such knowledge transfer and skills development to the marketplace of organizations that hire business and engineering school students (Hawkins, et al).

Teaching sustainability skills for infrastructure design and operations, and a host of other topics, cannot be a one-size fits all proposition. Common principles are needed, but the integration of sustainability into the core engineering curricula should be flexibly implemented by individual universities to reflect their core competencies and ensure compatibility with course syllabi.

References

Ascher, K., Principal, Happold Consulting, Interview with author, September 10, 2013.

Hawkins, N.C., Patterson, R.W., Mogge, J., and Yosie, T. F., "Building a Sustainability Road Map for Engineering Education," *J. Sustain. Chemistry & Engrg*, ACS, 2014, 2(3), 340-343.

Ingersoll Rand-SC Johnson press release: http://3blmedia.com/News/Sc-Johnson-Ingersoll-Rand-And-World-Environment...

PlaNYC 2014: www.nyc.gov/planyc

© ASCE 2014

Rauhe, B.R., Principal Technical Staff, Walt Disney Imagineering Research & Development, Inc., Interview with author, September 10, 2013.
San Francisco Public Utilities Commission Wastewater Enterprise, "Triple Bottom Line (TBL)," October 11, 2012.
Taival, D., Ingersoll Rand, Interview with author, September 10, 2013.
Yosie, T. F., Interviews with petroleum industry environmental executives 2012-2013.

© ASCE 2014

Exploring infrastructure solutions through bio-inspired, adaptable, structural art

Diana A. Chen[1], Brandon E. Ross, PE, PhD[2], and Leidy E. Klotz, PhD[3]

[1]Department of Civil Engineering, Clemson University, 139 Lowry Hall, Clemson, SC 29634; email: dachen@clemson.edu
[2]Assistant Professor, Department of Civil Engineering, Clemson University, 310A Lowry Hall, Clemson, SC 29634; email: bross2@clemson.edu; web: learningbuildings.com
[3]Associate Professor, Department of Civil Engineering, Clemson University, 208 Lowry Hall, Clemson, SC 29634; email: leidyk@clemson.edu; web: essoresearch.org

ABSTRACT

The deficiencies in safety and functional obsolescence of U.S. infrastructure call for innovative solutions to end this crisis. Biomimicry, the imitation of nature's patterns and strategies, may be one approach towards adaptable infrastructure that is continually safe and relevant. This paper describes a project-based course that has been developed to engage students in exploring bio-inspired, adaptable solutions through structural art. Students work together in an interdisciplinary team to learn about current problems in and potential solutions to our infrastructure crisis. This project culminates in a sculpture that is designed, constructed, and presented by the students to illustrate their understanding and proposed solution to these issues, where the objective of the structure itself is to increase public awareness of bio-inspired and adaptable infrastructure solutions.

Keywords: biomimicry, adaptability, structural art, interdisciplinary, self-directed project, project-based learning

INTRODUCTION—WHY ADAPTABILITY MATTERS AND HOW ART CAN HELP COMMUNICATE THIS

The infrastructure crisis in the United States is immediately evident by the report card released by the American Society of Civil Engineers in March 2013: the highest rating on the card was a B- (on a standard A-F grading scale), with 11 of the 16 categories rating D+ or lower (American Society of Civil Engineers, 2013). However, our infrastructure is not only deficient in meeting our needs in safety; it is also not meeting our service needs. A study in Minnesota found that only about 40% of building demolitions were due to physical condition; the rest were due to a lack of suitability for desired use (The Athena Institute, 2004). The Environmental Protection Agency funded a study in 1998 that inadvertently shed light on the wastefulness of American culture and habits: The study evaluated the reuse of materials to preserve the embodied energy and carbon already invested in them, thus imagining construction wastes as valuable resources. Then, examining the materials flow in construction, it was found that the overwhelming majority (92%) of these resources are being generated from renovations and demolitions, not from construction as expected (EPA Region 9, 2010). Unfortunately, these valuable materials are going to waste, as most our buildings haven't been designed to allow for the deconstruction and reuse of components. To address these glaring deficiencies in our buildings and infrastructure, we need to enable aspiring engineers with tools for generating innovative ideas but also a solid foundation of how to design sustainably. As Albert Einstein said, "The world we have created today as a result of our thinking thus far has problems which cannot be solved by thinking the way we thought when we created them" (Einstein & Calaprice, 2005).

Our current design philosophy for infrastructure is predictive—we design based on our assumptions of what loads a structure might need to withstand in its lifetime. However, we live in a dynamic era where our societal growth is causing unprecedented change, and progress is constantly in flux. With climate change, urbanization, terrorist threats, and transformative information technology, it no longer makes sense for our structures to remain static while everything around them changes. Our next-generation infrastructure needs to be adaptable to accommodate the undeniable change that is to come.

But what does adaptability look like in infrastructure, and how do we achieve it? Infrastructure design has evolved into a field that attempts to quantify nature's forces, but we can also imitate and learn from nature through "biomimicry", drawing sustainability and resilience concepts from nature-evolved patterns and strategies. The use of biomimetic designs has been on the uptake in the engineering community and has been successfully applied to various challenges in disciplines such as materials science ("Biomimicry to the rescue," 2009), fluid dynamics (Saha & Celata, 2011), computer science (Ratnieks, 2008), biomedical engineering (Zhang, 2012), and even the culinary arts (Burton, Cheng, Vega, Andrés, & Bush, 2013), among others. Yet, little research has been done with biomimicry in large-scale infrastructure.

One approach to enabling biomimetic design in infrastructure is to introduce biomimicry concepts at the component level. To investigate this approach, a project-based course was created to teach undergraduate students about these issues in infrastructure in exchange for their creative ideas. Not only is the course a dissemination method of educating young engineers about current challenges in the field, but it is also an approach to help prepare them for what the reality of working in industry might look like; by creating interdisciplinary teams by drawing from fields such as engineering, architecture, and the sciences, students gain experience of working with those outside of their field and who may not understand their technical language. As multidisciplinary approaches have been shown to be effective in the medical field (Mental Health Commission, 2006), this bridging of gaps between fields in the construction industry may also facilitate the development of more efficient and effective infrastructure.

To facilitate communication across technical vernaculars, art was chosen as the medium to explore and communicate the intersection of biomimicry, adaptability, sustainability, and resilience in infrastructure. Art, as a universal language, helps to

© ASCE 2014

build bridges of understanding between cultures (be it historical, ethnic, or of academic disciplines) and encourages collaborative creativity (Eger, 2011). Art has also been used as a tool for teaching English language learners other subjects: a subdivision of the New York State Education Department has observed how art can help students articulate science concepts through drawings and also how it can be used as medium for engaging students in making scientific connections (New York State Education Department, Office of Bilingual Education and Foreign Languages Studies, 2010). While science and engineering have specific goals, artistic projects tend to be more open-ended. This flexibility is important for personal expression and allows for creative, unplanned outcomes. While art may not contribute to resolving the research questions at hand, using an artistic approach may create positive impacts down the road in providing collaborative research experiences (Legrady, 2006). Dr. F. Robert Sabol, a professor at Purdue University, said that "art allows people to communicate across time and space. Art education teaches us how to understand and use this language in our dialog with the rest of humanity as we explore who we are or strive to be" ("Board of Directors," 2013). Using art as the educational platform for this project aligns with the objective of promoting creativity—an essential element to the innovative solutions our infrastructure needs.

COURSE OVERVIEW

The Creative Inquiry (CI) program at Clemson University allows undergraduate students to form small groups and tackle problems that spring from their own curiosity. These investigation-based groups are typically mentored by a graduate student or faculty member and usually span two to four semesters. The student-led approach engages students and allows them to take ownership of their projects ("Creative Inquiry and Undergraduate Research," 2014).

Through the CI program, a group of undergraduate students are working in an interdisciplinary team to study "Bio-Inspired Adaptable Structures." This investigation bridges various fields to help students learn about problems in infrastructure. Interdisciplinary collaboration is encouraged through a common interest in the natural world and by communicating through the universal language of art. Students from majors such as engineering, architecture, and the sciences are tasked with looking to nature for examples of adaptable structural forms and processes, and then integrating these forms and processes by designing and building a structural art sculpture that communicates bio-inspired solutions for adaptable infrastructure design.

As part of this process, students will perform three interrelated tasks:

i. identify and analyze structural forms and processes in nature that feature adaptation,
ii. design and construct a piece of bio-inspired structural art that exhibits adaptive uses and behavior, and
iii. exhibit the work at the one or more cultural art festivals in the surrounding area.

© ASCE 2014

While the project's guidelines are designed to follow the regulations of the Piccolo Spoleto festival in Charleston, SC, there are many venue options. The Piccolo Spoleto festival is an annual opportunity for local and regional artists to exhibit their work. With over 15,000 visitors annually, this festival is an ideal venue to increase public awareness of adaptable infrastructure solutions. Other potential venues include Artisphere in Greenville, SC, a signature art festival in the region, and nearby rural festivals, which may provide opportunities for community outreach efforts.

The course is divided into three modules based roughly on the tasks listed above. In the first module, students write weekly reflections and participate in regular discussions based on targeted readings that introduce problems and possible solutions for current and future civil infrastructure. Adaptability through biomimicry and designing for deconstruction are the primary contexts used in this course for seeking and discussing potential solutions. During the second module, students formulate ideas, create sketches, and use engineering modeling tools to create technical diagrams for the prototyping process. After evaluating and refining the prototypes, students choose a final design, create technical drawings, and begin construction. Students complete the construction of the final design in the third module and will present their work at one or more art festivals in Spring 2015. The public demonstration will include an illustration of why the design is related to issues in infrastructure. This project addresses problems in civil engineering by drawing from arts, natural sciences, and societal issues and requires students to use critical thinking to justify the connections they make.

LEARNING OBJECTIVES AND ACTIVITIES

A small group of students (around four to six) has been an effective size for this course, making close collaboration and a flexible class structure feasible—an optimal environment for engaging students and providing them with the opportunity to design their own curriculum. Readings, discussions, and activities include topics such as creativity and collaboration, biomimicry, biophilia, structural art, structural adaptability, and designing for deconstruction. Art and thinking critically about nature are introduced early in the course and are used as foundational examples for many activities. Students are encouraged to share artwork, relevant articles, and provide activity ideas with the group.

An overview of the course content is shown in Tables 1-3, which contain work already completed and planned in the authors' current class. Content is grouped by teaching/learning objectives and are listed alongside select activities that are performed to achieve these objectives. The tables also include references for student reading assignments and texts used to create course content, when applicable. A detailed account of the class meeting highlighted in gray is presented in the next section to demonstrate how the information in the table is expanded into a lesson plan. The current status of the class is indicated in Table 2.

© ASCE 2014

Table 1: A chronological representation of course objectives, sample activities, and relevant references (Module 1, completed)

Objectives	Sample Group Activities	Assignment Refs.	Teaching Refs.
Introduce participants and establish tone for course	Ice-breaker activity; Discuss syllabus and course expectations; Establish personalized group guidelines		Tuckman's team development model
Be able to apply the theory of "reframing" to various scenarios	Discuss "strange" art and how this relates to reframing; Practice refining engineering design project statements by reframing the problem	(Seelig, 2012c)	E4 Course, Harvey Mudd College; Prof. Lori Bassman (personal comm.)
Introduce concept mapping; **Practice different roles of constructive team members**	Create a concept map of course-relevant terms; Use concept map to develop a hypothetical design problem; Cycle through "thinking hats" and build on the design problem	(Seelig, 2012b)	(Trochim, 1989); (De Bono, 1999)
Initiate first stage of student research; **Initiate first stage of student presentations;** **Discuss group biases towards project solution**	Find examples of biomimicry in both art and technology; share these findings with the group; Hold class outdoors (employ biophilic benefits and allow for creative inspiration); Brainstorm biophilic designs; share these with the group	(J. M. Benyus, 2002); (*Biomimicry in action*, 2009); (*Biomimicry's surprising lessons from nature's engineers*, 2005); (J. Benyus, 2008); (Heerwagen, 2009)	(Seelig, 2012a)
Illustrate practical relevance of sustainability concepts; **Discern sustainability topics as current issues**	"Show and tell" examples of deconstructability in common objects; Participate in a two-part Design for Adaptability and Deconstruction craft; Recognize the critical state of infrastructure; Clarify differences between architecture, structural engineering, and structural art	(Webster, 2007); (Brand, 1995); (*Flow*, 1997), etc.; (American Society of Civil Engineers, 2013); (Billington, 1985)	(Reid, 2008)

© ASCE 2014

Table 2: A chronological representation of course objectives, sample activities, and relevant references (Module 2, in progress)

Objectives	Sample Group Activities	Teaching Refs.
Begin brainstorming; **Practice biomimetic searching for solutions** **Refine design ideas**	Identify and list project details (bio-inspiration, structural function and form); Use common resources to perform simple biomimetic problem-driven or solution-driven searches Introduce and apply design objectives, functions, and constraints Introduce and implement a morphological chart	(Dym, Little, Orwin, & Spjut, 2008) AskNature.org
Finalize project definitions; **Introduce engineering project management tools**	Use semester's practice of problem statement analysis to construct individual problem statements Provide instruction on how to create and use a Gantt chart and work breakdown structure	E111-113 Courses, Harvey Mudd College
Practice individually presenting; **Select a few intermediate designs**	Create preliminary design sketches; Divide up initial ideas to research and flesh-out individually; Present these findings to the group; Discuss and select designs to pursue	
Incomplete below this line		
Hold a design review; **Practice formal presentation skills**	Invite students from other disciplines (e.g., architecture) to participate in a design review to help brainstorm and refine existing ideas; Practice presenting technical information to a non-technical audience	
Create technical drawings of design options	Hold a tutorial on how to use computer-aided design software	
Prototype design options; **Select a final design**	Create architecture-type three dimensional models to demonstrate concepts	

© ASCE 2014

Table 3: A chronological representation of course objectives, sample activities, and relevant references (Module 3, incomplete)

Objectives	Sample Group Activities
Construct and continue to refine final design	Provide a closed-off space that can be used as the team's work station; Determine necessary building materials, tools, and other resources Obtain or provide requested resources
Present final sculpture at one or more festivals	Hold multiple demonstrations to practice presenting and increase outreach impact Illustrate value of sustainable structural aspects to audiences; Implement media assessment and collect results

Lesson Plan Example: Six Thinking Hats

While the tables above provide a rough outline of the course content, there are nuances regarding the teaching and learning process just as—if not more—important than the content that should be considered. Often, these nuances will determine the success or failure of the class based on how they are expressed in the activities. A fuller description of one class period's lesson plan is illustrated here to demonstrate details that an instructor should pay attention to for encouraging student engagement. However, thorough descriptions of all lessons are not provided since educators each have their own teaching style and may have their own preferred activities to achieve the listed objectives. The class meeting described in this lesson plan sets the stage for including creativity in this project—a crucial feature for developing innovative infrastructure solutions.

Edward de Bono, in his book *Six Thinking Hats*, discusses how lateral thinking can be a tool for groups to think and plan more effectively. The six different colored hats each represent a role that we play when working in a team, and we often have one or two hats that dominate over the others. These are summarized by Tina Seelig in her book *inGenius: A Crash Course on Creativity* as follows.

- A person who is drawn to the facts and is very logical wears the *white* hat.
- A person most comfortable generating new ideas wears the *green* hat.
- A person who uses intuition to make decisions wears the *red* hat.
- A person who is very organized and process-oriented wears the *blue* hat.
- A "devil's advocate," who uncovers what won't work, wears the *black* hat.
- A person eager to make everyone happy wears the *yellow* hat. (Seelig, 2012b)

Consistent with the theme of providing creative artistic outlets, students are each provided six index cards and asked to decorate and label them as they wish, representing the six different colors of the thinking hats. Students are given ample time to personalize their cards while materials are distributed and logistical topics are discussed.

Subsequently, a few minutes (three to five) are set aside for a quick brain warm-up exercise, such as Telephone Pictionary—a game that involves both creativity and drawing and is apt to quickly become silly through misinterpretation. Brain warm-up exercises help participants switch from a work mindset to brainstorming, where a solution isn't always clear. These short exercises warm up the imagination similar to the way a runner warms up before a race (Seelig, 2012a).

Students then are asked to concept map ideas that they associate with the class project, be it from the syllabus, from personal communication, or preliminary solutions they had formed in their minds. Although performed prior to the completion of the necessary background knowledge for the project, this exercise helps the group to gain a rough understanding of what each team member imagines to be relevant or important to the project. Concept mapping is a technique that helps the user visualize relationships between various concepts within a topic. Concept mapping typically begins with a list of brainstormed concepts which can be rearranged on a page. As lines and arrows or other branches are drawn between the concepts, the nature of the

© ASCE 2014

relationships can be written directly on the map. (For more information, see Trochim, 1989). This exercise introduces the idea of collecting and organizing related topics and identifying relationships between them—indicating an understanding of the problem is an important precursor to being able to brainstorm solutions. Some significant aspects to note in this activity are that students are asked to stand and interact with each other by drawing on a blank whiteboard, and each student has their own marker. These characteristics are drawn from Seelig's chapter on brainstorming guidelines. Seelig emphasizes the importance of standing, as it triggers energy and engagement, and open room to move and write, since ideas are often limited by the available space. Moreover, while seemingly trivial, it is important for each participant to have their own outlet for writing ideas down. This avoids the "tyranny of the pen," the phenomenon where a designated recorder personally filters ideas before writing down the "good" ones, and also speeds up the brainstorming process (Seelig, 2012a).

The objective of this class is to have students practice their "teammate role playing" in an informal setting with a fabricated problem to prepare them for group work later in the course and beyond. The concepts and relationships they produce, although possibly incoherent due to the premature nature of the assignment, indicate which topics students have internalized and are used as the foundation for the role playing exercise. The team chooses to examine a group of two or more concepts and their relationships and treats this as their assigned problem statement. The imperfect yet intentional timing of the assignment allows for more open-ended ideas, which gives way to generous student engagement. Given this problem statement, students are tasked with further developing the imaginary project by wearing their respective hats. Students are asked to order their thinking hats in order of most comfortable to least comfortable, and these roles are cycled through such that each round of role playing is more difficult for each student. Group members are encouraged to help generate viewpoints when the participant on the spot is having trouble performing a particular role. As the turns pass from student to student, additional features are added to the "final project," culminating in a cohesive, albeit wild, suggested deliverable. The concept map students developed and used in this case study is shown in Figure 1. Topics listed by the students in the concept map include expected terms such as "structure," "design," "architecture," "sustainable," and "adaptable," and also creative additions such as "modular," "art history," "skeleton," and "photosynthesis."

Figure 1: Concept map developed by students

© ASCE 2014

CURRENT STATUS AND FUTURE PLANS

The first module of the course, which covered background information on various topics integral to the project, was completed in March 2014. In addition to the lesson plan described in the previous section, the first module included activities such as hands-on projects to stimulate designing for adaptability and deconstruction (Figure 2). In this activity, students were tasked with designing their building components (20 index cards and yarn) to be adaptable, have the ability to be disassembled, and be functional in two separate structures (without significant alteration to the components after assembly begins, mimicking a more realistic design and construction process).

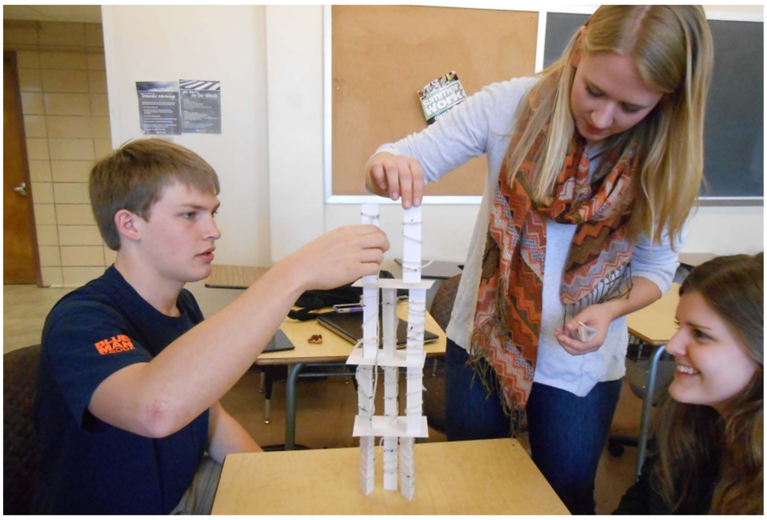


Figure 2: Students work on *Designing for Adaptability and Deconstruction* craft

At the end of the first module, the students spent some time determining their project's definitions by refining the initial problem statement to limit what they plan to tackle. For example, including a budget, and choosing and following a festival's guidelines, can help to identify certain project limitations. Much of the first module involved dissecting and analyzing complete engineering problem statements, so this final assignment culminated in students using and applying their practiced analysis tools. Since the end of the first module, students have begun the brainstorming process and will begin prototyping shortly. The brainstorming process is an iterative process that involves individual idea-generating and sketching, sharing within the group, and group decisions about which ideas to pursue and research, until a few cohesive ideas have been developed and settled on. At this point, students will make technical drawings of the design options and begin the prototyping process. When the feasibility and success of the prototypes are shown, the students will choose a final design and begin construction. The resulting teaching module for exploring biomimetic, infrastructure adaptability through structural art and the students' learning outcomes will be shared with other educators. A public demonstration is planned to be held at the Piccolo Spoleto festival in Charleston, SC and other venues to present the structural form created by the students and to increase public awareness of adaptable infrastructure solutions.

Assessment

The difficulties of evaluating the learning outcomes of a problem-based learning approach have been illustrated in many engineering education studies (e.g., (Prince, 2004)), and this course is no exception. In addition, the authors were wary of adding unnecessary assessments that would intrude on the learning process. For these reasons, assessment of student learning is designed to occur as follows, and traditional written exams are not administered. Students demonstrate their understanding of the material through weekly written reflections and in-class discussions. Furthermore, a clear grasp of the foundational material is necessary for the project's progress, and therefore any negligence or misunderstandings are apparent and can be addressed immediately.

One form of evaluation pertinent to this course, however, is the assessment of the experience the students are having based on the project's learning objectives. For the first module, educators may consider one-on-one discussions or written reflections with students before and after the module to determine whether their understanding of the foundational material has improved. For the second module, students can have periodic check-ins with the instructor to ensure that they are approaching the design process correctly (e.g., exploring all possible design options, mastering computer-aided drawing software, etc.). This informal assessment style will act both as a method of evaluation and an opportunity for students to acknowledge their struggles and ask for assistance. Simply making it to the end of the course and having physical deliverables will be a valuable achievement, and students will be asked to reflect on their journey throughout the course to summarize and appreciate the various soft and technical skills they gained from this project.

In addition to evaluating student learning outcomes, the outreach goals of the class will also be assessed. The project's outreach goals are to promote awareness of adaptable infrastructure solutions and help educate the public about biomimicry, adaptability, and other sustainable and resilient construction design methods. To do so, a form of media will be incorporated into the final sculpture's presentation that will allow visitors and passers-by to document what they saw or thought. This media will be similar to a QR code that individuals can scan, or a "photo check-in" of the sculpture, that can document a rough number of visitors and to get an impression of what visitors learned. The specific assessment technique will be designed by the students as an integral part of the display, and will be implemented to collect feedback at the festival. This assessment is meant to help evaluate the degree to which the project communicated the intended message to the public.

REFERENCES

American Society of Civil Engineers. (2013). *2013 Report Card for America's Instructure*. Retrieved from http://www.infrastructurereportcard.org/a/documents/2013-Report-Card.pdf

Benyus, J. (2008). A Good Place to Settle: Biomimicry, Biophilia, and the Return of Nature's Inspiration to Architecture. In *Biophilic design: the theory, science, and practice of bringing buildings to life* (p. 385). Hoboken, N.J: Wiley.
Benyus, J. M. (2002). *Biomimicry: Innovation Inspired by Nature*. New York: Harper Perennial.
Billington, D. P. (1985). *The tower and the bridge the new art of structural engineering*. Princeton: Princeton university press.
Biomimicry in action. (2009). Retrieved from http://www.ted.com/talks/janine_benyus_biomimicry_in_action.html
Biomimicry to the rescue. (2009, March 19). *Materials Today*. Retrieved February 25, 2014, from http://www.materialstoday.com/crystalline-materials/news/biomimicry-to-the-rescue/
Biomimicry's surprising lessons from nature's engineers. (2005). Retrieved from http://www.ted.com/talks/janine_benyus_shares_nature_s_designs.html
Board of Directors. (2013). *National Art Education Association*. Retrieved from http://www.arteducators.org/about-us/board-of-directors
Brand, S. (1995). *How buildings learn: what happens after they're built*. New York: Penguin Books.
Burton, L. J., Cheng, N., Vega, C., Andrés, J., & Bush, J. W. M. (2013). Biomimicry and the culinary arts. *Bioinspiration & Biomimetics*, *8*(4), 044003. doi:10.1088/1748-3182/8/4/044003
Creative Inquiry and Undergraduate Research. (2014). *Clemson University*. Retrieved from http://www.clemson.edu/academics/programs/creative-inquiry/
De Bono, E. (1999). *Six thinking hats* (1st Back Bay pbk. ed., rev. and updated.). Boston: Back Bay Books.
Dym, C. L., Little, P., Orwin, E. J., & Spjut, R. E. (2008). *Engineering design: a project-based introduction*. Hoboken, N.J.; Chichester: Wiley ; John Wiley [distributor].
Eger, J. M. (2011, January 11). If Art Is a Universal Language. *The Huffington Post*. Retrieved February 25, 2014, from http://www.huffingtonpost.com/john-m-eger/if-art-is-a-universal-lan_b_806787.html
Einstein, A., & Calaprice, A. (2005). *The new quotable Einstein: enlarged commemorative edition published on the 100th anniversary of the Special Theory of Relativity*. Princeton: Princeton U.P.
EPA Region 9. (2010). *Design for Deconstruction* (No. X1-96912701). Retrieved from http://www.epa.gov/region9/greenbuilding/pdfs/DesignForDeconstrManual.pdf
Flow. (1997) (Vols. 1-6, Vol. 1). Retrieved from http://www.youtube.com/watch?v=AvEqfg2sIH0&feature=youtube_gdata_player
Heerwagen, J. (2009). Biophilia, health, and well-being. *Restorative Commons: Creating Health and Well-Being through Urban Landscapes, USDA Forest Service, Pennsylvania*, 39–57.
Legrady, G. (2006). Perspectives on Collaborative Research and Education in Media Arts. *Leonardo*, *39*(3), 214–218.

© ASCE 2014

Mental Health Commission. (2006). *Multidisciplinary Team Working: From Theory to Practice*. Retrieved from http://www.mhcirl.ie/File/discusspapmultiteam.pdf

New York State Education Department, Office of Bilingual Education and Foreign Languages Studies. (2010). *Art as a Tool for Teachers of English Language Learners*. Retrieved from http://www.p12.nysed.gov/biling/docs/Art_as_a_Tool-for_Teachers.pdf

Prince, M. (2004). Does Active Learning Work? A Review of the Research. *Journal of Engineering Education*, *93*(3), 223–231. doi:10.1002/j.2168-9830.2004.tb00809.x

Ratnieks, F. L. W. (2008). Biomimicry: Further Insights from Ant Colonies? In P. Liò, E. Yoneki, J. Crowcroft, & D. C. Verma (Eds.), *Bio-Inspired Computing and Communication* (pp. 58–66). Springer Berlin Heidelberg. Retrieved from http://link.springer.com/chapter/10.1007/978-3-540-92191-2_6

Reid, R. L. (2008). The Infrastructure Crisis: Special Report. *Civil Engineering*. Retrieved from http://www.asce.org/Content.aspx?id=25562

Saha, S. K., & Celata, G. P. (2011). Advances in modelling of biomimetic fluid flow at different scales. *Nanoscale Research Letters*, *6*(1), 1–11. doi:10.1186/1556-276X-6-344

Seelig, T. L. (2012a). Build, Build, Build, Jump! In *InGenius: a crash course on creativity* (1st ed., pp. 47–64). New York: HarperOne.

Seelig, T. L. (2012b). Marshmallow on Top. In *InGenius: a crash course on creativity* (1st ed., pp. 135–147). New York: HarperOne.

Seelig, T. L. (2012c). Spark a Revolution. In *InGenius: a crash course on creativity* (1st ed., pp. 17–30). New York: HarperOne.

The Athena Institute. (2004). *Minnesota Demolition Survey: Phase Two Report, Prepared for: Forintek Canada Corp*. Retrieved from http://briscoman.com/sites/default/files/Athena_Demolition_Survey.pdf

Trochim, W. M. K. (1989). An introduction to concept mapping for planning and evaluation. *Evaluation and Program Planning*, *12*(1), 1–16. doi:10.1016/0149-7189(89)90016-5

Webster, M. D. (2007). Structural Design for Adaptability and Deconstruction: A Strategy for Closing the Materials Loop and Increasing Building Value (pp. 1–6). American Society of Civil Engineers. doi:10.1061/40946(248)27

Zhang, G. (2012). Biomimicry in biomedical research. *Organogenesis*, *8*(4), 101–102. doi:10.4161/org.23395

© ASCE 2014

Infrastructural Ecologies: A Macroscopic Framework for Sustainable Public Works

Hillary Brown, FAIA Author[1]

[1] Bernard & Anne Spitzer School of Architecture, the City College of New York, 141 Convent Avenue, 3M14, New York, NY 10031; (212) 650-6187; email: hbrown2@ccny.cuny.edu;

ABSTRACT

"Infrastructural ecology" is described here as a planning and design framework that promotes beneficial exchanges across the energy, water, waste, and transportation service sectors to reduce collective system costs, improve performance and reduce environmental and social impacts. Patterned on the workings of natural ecosystems, infrastructural ecology fosters synergies through proactive colocation or otherwise networking of different sector systems. Asset design may also capitalize on adjacent or local land-uses, and utilize untapped constructed or natural system resources. Infrastructural facilities may incorporate other commercial, cultural or even recreational amenities to address community sensitivities while fostering job creation. Ultimately more sustainable, such networked infrastructure facilities are integrated, multipurpose and synergistic; they reduce carbon intensity and GHG emissions; assimilate the free work of natural systems; and can enhance the community in which they are situated. Descriptions of several successful case studies around the world exemplify these ideas and reveal important co-benefits that accrue to each project's triple bottom line.

Infrastructural Ecologies defined as a higher-level systems approach

Deteriorating water, energy, waste, sanitation, communications and transportation assets across the US, many nearing the end of their useful life, demand significant national reinvestment. This fact – accepted differentially across the political spectrum—offers us a window of opportunity to reexamine the paradigms within which critical lifeline systems are designed, built and operated.

Current public works paradigms hold to the prevailing "silo-ing" of the energy, waste and water sectors; they advocate for improving the performance of infrastructural assets by *optimizing their parts.* Sticking with these regimens, we may forego many opportunities only grasped at a more macro-scale and from a systems perspective. Here we can look at the interdependencies and beneficial synergies *across* sectors and systems, both constructed and natural. "Infrastructural ecology" is one model offered here for re-envisioning critical systems that advance the tenets of sustainability. It is exemplified by a series of innovative projects that are: 1) integrated, multipurpose and synergistic vs. segregated; 2) low carbon; 3)

© ASCE 2014

incorporating the work of natural systems that cool air, clean water, provide power, digest and de-toxify waste; and 4) planned to enhance the existing community.

Direct correspondences exist between man-made systems and the natural ones that provide our fuel, regulate climate and floods, and purify water, etc. As extensions of interacting natural processes, socio-technical energy, water, transport, communications and waste services, moreover, are *intrinsically networked* systems. The "energy-water nexus," for example, describes the interdependencies whereby energy production is contingent on water use, just as water treatment and distribution systems consume non-trivial energy. With climate instability, however, this co-dependency is ignored at our peril. Both concepts, first, the alignment of constructed systems with natural (and social), and second, the cycling of energy and matter (coupling systems across sectors) are encompassed in the term infrastructural ecology (Brown, 2009, 2014; Pandit et al. 2011, Xu et al, 2010, 2012).

Infrastructural ecology can be promoted by the spatial colocation of different system services. Physical proximity allows for reciprocal exchanges among energy/water/waste systems (municipal, domestic *and* agricultural) to reduce throughput of matter and energy (Brown, 2014). Infrastructural ecology in this way helps decouple carbon-intensive technologies while solving waste pollution problems (figs. 1- 6) Another dimension of infrastructural ecology, achieved through thoughtful design and colocation, is the amelioration of unwanted aspects of these assets (both perceived and real). Contested waste-transfer stations, water-treatment plants, electrical-transmission towers, and gas-fired power plants *can* best find local acceptance not only through comprehensive mitigation, but also through context-sensitive design practices, the incorporation of other commercial or public amenities, and using processes that embrace the community as a valued partner in facility development. (Mt. Poso example, figs. 4, 6.)

From Industrial- to Infrastructural Ecology: a model transposed

Modeled on ecosystem interdependencies, "eco-industrial parks" adhere to the tenets of industrial ecology by clustering facilities to capitalize on the efficiencies of linked energy and material flows. (Industrial ecology is the multidisciplinary study of material and energy flows through industrial systems). Initiated in 1989, a well-known exemplar is the ecology demonstrated in Kalundborg, in Denmark (fig. 1), (Jacobsen 2006; Chertow 2007). Kalundborg was developed around a coal-fired powerplant whose waste steam and hot water feed an oil refinery and pharmaceutical company while warming greenhouses, a fish farm and area homes. Fly ash from its stacks, which substitutes for virgin gypsum in a sheetrock manufacturing plant, also is one of 22 separate exchanges counted as of 2011 (Domenech and Davies 2011). The eco-industrial park's initial $ 60 million investment has returned $15 million in annual savings, eliminated 64,000 tons of CO_2, while reducing air, water and soil pollution (Domenech and Davies 2011).

© ASCE 2014

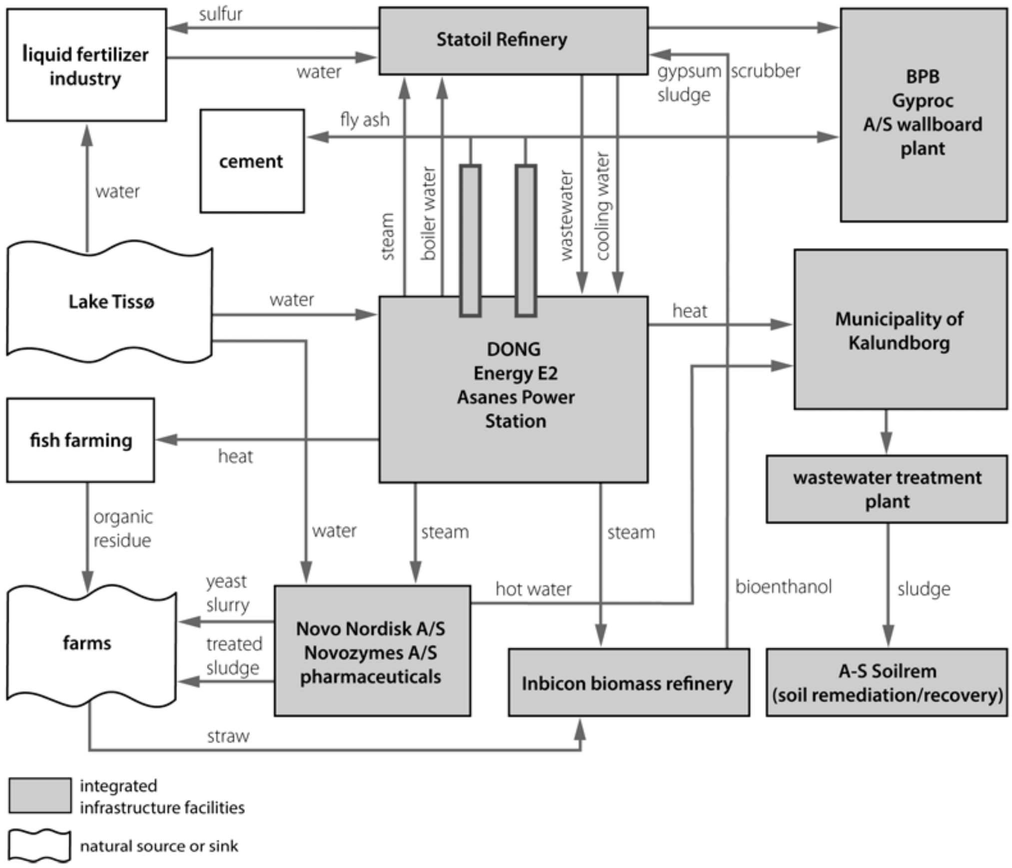


Figure 1. Kalundborg Symbiosis, Kalundborg, Denmark. (Adapted by H. Brown from Jacobsen 2006, Domenech and Davies 2011, permission Island Press 2014)

To provide infrastructural services to the new Stockholm neighborhood of Hammarby Sjöstad (fig. 2), Stockholm officials developed a similarly circular archetype now called the "Hammarby Model" (Stockholm Municipality 1996). This new town initiative (to be completed by 2017) had modified existing and extended new infrastructure to reduce metabolic urban flows (Iveroth et al 2013). It implements connections across heat and power, sewage and waste handling utilities. Waste heat recovered from the sewage treatment plant is combined with that of the local wood-chip fired Combined Heat and Power (CHP) plant for district heating. The former's methane biogas is processed into cooking and vehicular fuel while its sludge plus agroforestry waste reverts to re-fertilize the forests. Photovoltaic arrays, fuel cells and solar thermal provide green power and hot water (Stockholm Municipality 2007).

© ASCE 2014

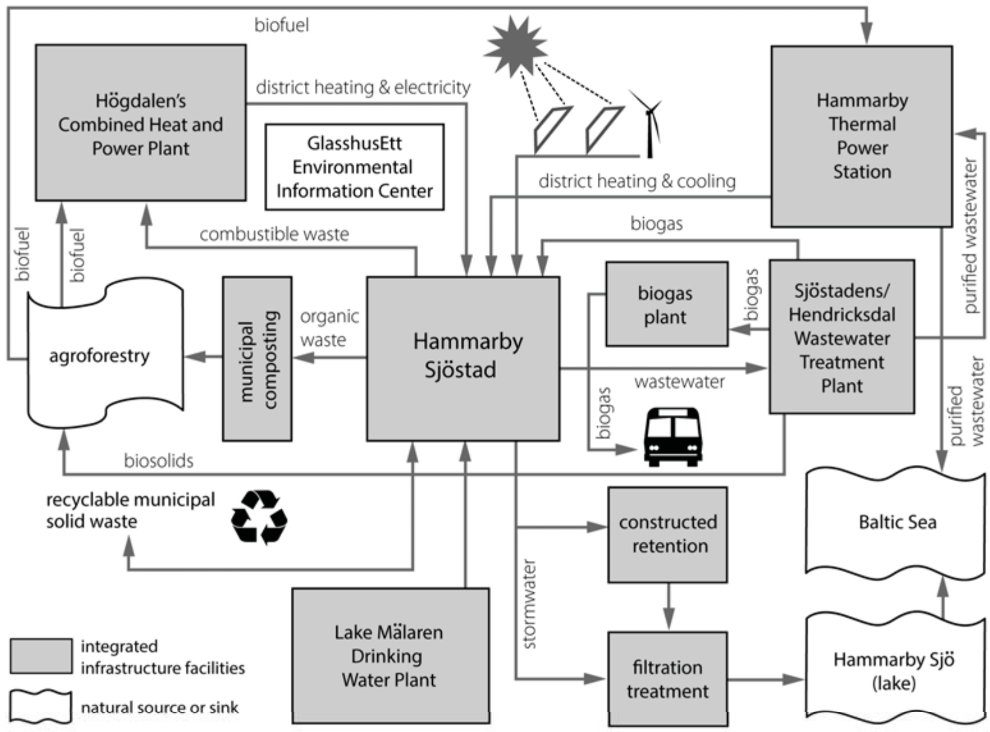


Figure 2. **The "Hammarby Model," Hammarby Sjöstad, Sweden. (Redrawn by H. Brown from an original by Lena Wettrén, Bumling AB., permission Island Press 2014)**

According to a recent accounting of outcomes, Hammarby generates 22% of its district heating, 24% of its cooling and 5% of electricity (Iveroth et al 2013). New public transit and bio-fueled buses reduce transportation energy 48% below comparable communities (Brick 2008). The abundance of biogas generated (538%) has created a surplus utilized far beyond the immediate district.

Whereas Hammarby Sjöstad has attracted visiting officials worldwide, its model has been replicated only incrementally to date. The first two infrastructure ecology examples below focus on localized exchanges designed across paired systems. The remaining studies demonstrate multiple exchanges.

Leveraging Local Resources: Cogeneration in Bakersfield, CA and at the University of New Hampshire

In 2012, the Mt. Poso Cogeneration Plant was converted from combustion of coal and coke to 100% local beneficial biomass. Sited adjacent to the Mt. Poso oil field, the existing power plant already relied upon reciprocity: oil-recovery is utilized for its electricity and steam, while the condensate retrieved from the fields cools the power plant. Prompted by California's aggressive Renewable Portfolio Standard, Mt. Poso Cogeneration Co., LLC looked for a substitute and found nearby biomass-rich

© ASCE 2014

nut orchards, crop-agriculture, dairy, and forest regions. It receives annually 335,300 tons of biomass waste generating 44 MW of power (Hyams 2012). The wood ash byproduct cycles back to the fields for soil enrichment; some is also scattered on dairy farm pastures to prevent hoof disease. In addition to major CO_2 reductions and air quality improvements (biomass is no longer burned openly in fields), local employment has increased by 30%, given the relative labor-intensity of biomass collection, processing and transport at the plant.

The University of New Hampshire similarly cast its eye locally for suitable energy resources. In 2006, it embarked upon a unique joint venture with Waste Management of New Hampshire Inc. (WMI). At that time, WMI's annual deposition of solid waste was producing landfill-generated methane in excess of that consumed by two local 9 MW power plants, forcing WMI to flare the excess, a dangerous GHG. By arrangement and at a cost of $ 49 million, that surplus now fuels the University, which built a gas purification facility at the landfill, and pipes the biomethane 12.6 miles underground to its on-campus co-generation plant. This investment supplies up to 85% of the university's electricity, and the heat equivalent of 18,700 homes, saving an estimated 187 thousand metric tons of carbon equivalents. It has a ten-year payback, factoring in UNH's sale of excess power to the grid, and revenue from the sale of its Renewable Energy Certificates (US EPA 2010).

Assimilating Wastes: Biogasification in Lille, France

Driven also by carbon reduction imperatives, the City of Lille, France similarly capitalized on under-utilized local resources. Lille's ambitious 1996 Urban Mobility Plan targeted both a doubling of public-transit by 2015 and elimination of diesel fuel consumption (ICLEI Europe 2008). Supported by the European Commission's BIOMAXGAS program, the municipality built a new organic waste recovery facility (ORC) that performs controlled biodigestion of municipal organic matter (industrial, domestic, sanitary, and agroforestry). This is combined with recovered sewage gas to produce a renewable, high quality natural gas for its buses (fig 4).

© ASCE 2014

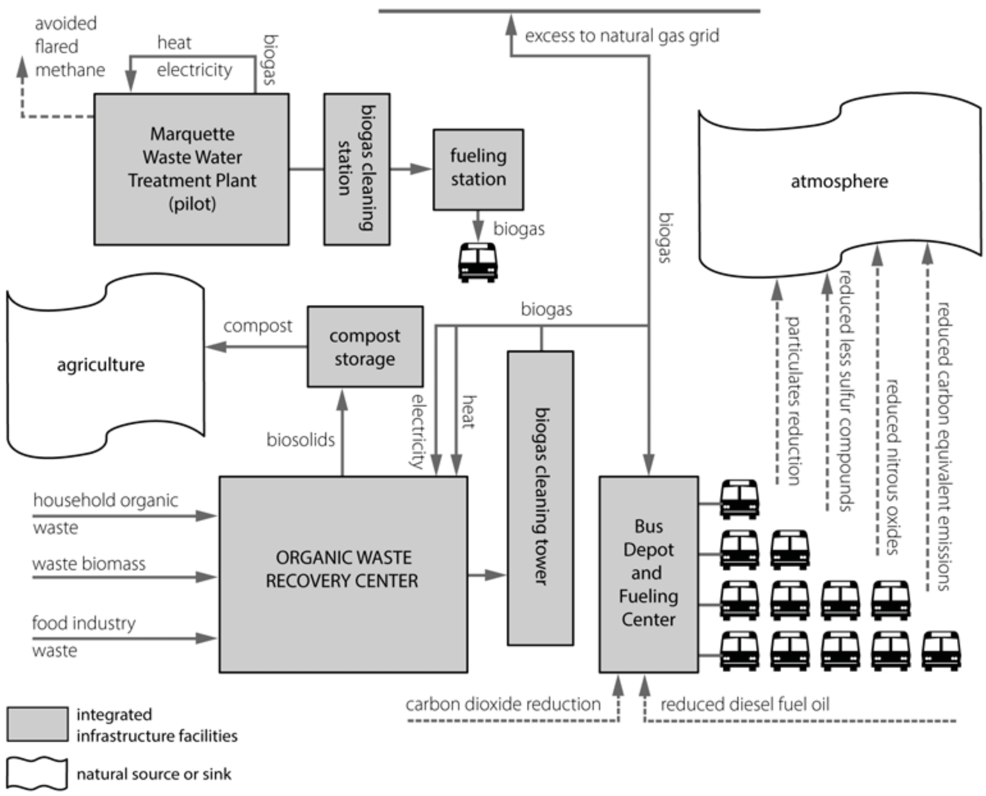


Figure 3. Lille Métropole Organic Waste Recovery Center and Transfer Center, Lille, France. (H. Brown, permission Island Press 2014.)

The biogas fuel eliminates about 40,000 gallons of diesel fuel annually for 150 buses and also averts the release of methane from both its wastewater and solid waste facilities (Lille Métropole Urban Community 2009). The residual sludge provides agricultural areas with 34,000 tons of compost annually. Lastly, the ORC is colocated with a bus refueling station *and* garage depot, eliminating vehicle miles previously expended for bus refueling. With renewable energy production, efficient waste elimination, the recycling of nutrients, and colocation of different facilities, the ORC solves several problems simultaneously, with subsidiary benefits.

Avoiding Local Resistance: *Isséane Energy-from-Waste, Paris, France*

In part, Lille's anaerobic biodigestion initiative was impelled by the European Union's 1999 stringent ban on landfilling organic material. That same directive, which progressively eliminates landfilling of many other materials (European Commission 1999), has promoted more widespread adoption of stringently controlled, co-generating Energy-from-Waste (EfW) plants. These use a closed-loop trash-to-renewable-energy cycle (Coffey 2011). (As of 2009, there were 420 EfW plants across Europe providing heat for 15.3 million households and electricity for 8 million).

Discretely sited on a former brownfield upriver from the Eiffel Tower, the 2008 Isséane Energy-from-Waste Plant (fig. 4) sorts, recycles and combusts municipal solid waste. Its 52 MW of power and heat serving 8,000 homes replaces 110,000 tons of fossil fuel. Barged instead of trucked to avoid 23 tons of CO_2 emissions annually, the waste slag is repurposed in roadbed construction (SYNCTOM 2011). Isséane's greatest achievement, however, is the use of innovative ameliorative strategies to foster local acceptance. To reduce visual and environmental impacts, four of the plant's 6 stories are depressed below grade. Its emissions stacks are barely visible above the green-roofed, wood-clad structure. An "environmental charter" developed with the affected community governs construction and operations. Locals hired as "sentinels" ensure it meets or exceeds stringent health and safety objectives. With its CHP from waste, productive use of residuals, and design and operating agreements deferential to the community context, SYNCTOM's exemplary plant routinely hosts waste-management experts from around the world.

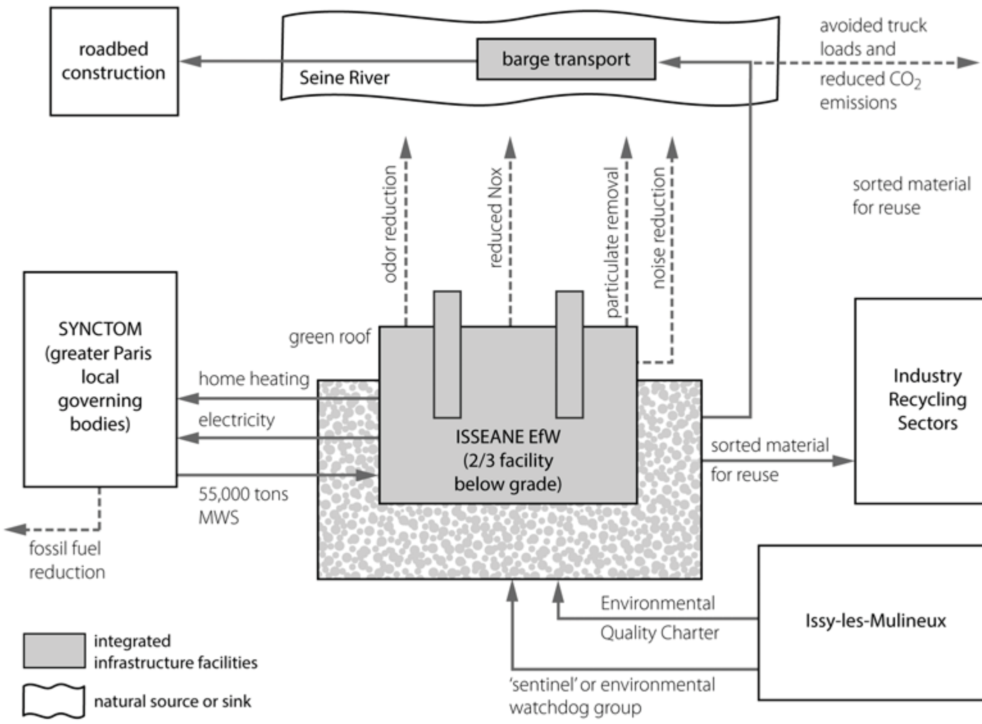


Figure 4. Isséane: Issy-les-Moulineaux Household Waste Sorting and Energy Production Center, Paris, France. (H. Brown, permission Island Press 2014)

Diversifying By-Products: The Svartsengi Resource Park, Iceland

Coupled with hydropower, Iceland's geothermal power plants produce 82 percent of the nation's 4,400 GWh of energy, and heat almost 90 percent of its homes. (Ragnarrsson 2010). The Svartsengi geothermal cogeneration plant's steam condensate supplies districting heating for 9 nearby towns and melts snow at nearby Reykjavik International Airport. The remaining brine feeds an adjacent surface pond today well-known as the "Blue Lagoon," now a spa. Colocated spin-offs that additionally comprise the Resource Park (fig. 5) include the spa's clinic, guest and conference facilities, aquaculture production, mineral (brine), and biotech research lab that studies the dermatologic and medicinal properties of the brine. Collectively, these facilities garner over $ 21 million in revenue annually (Gross 2008).

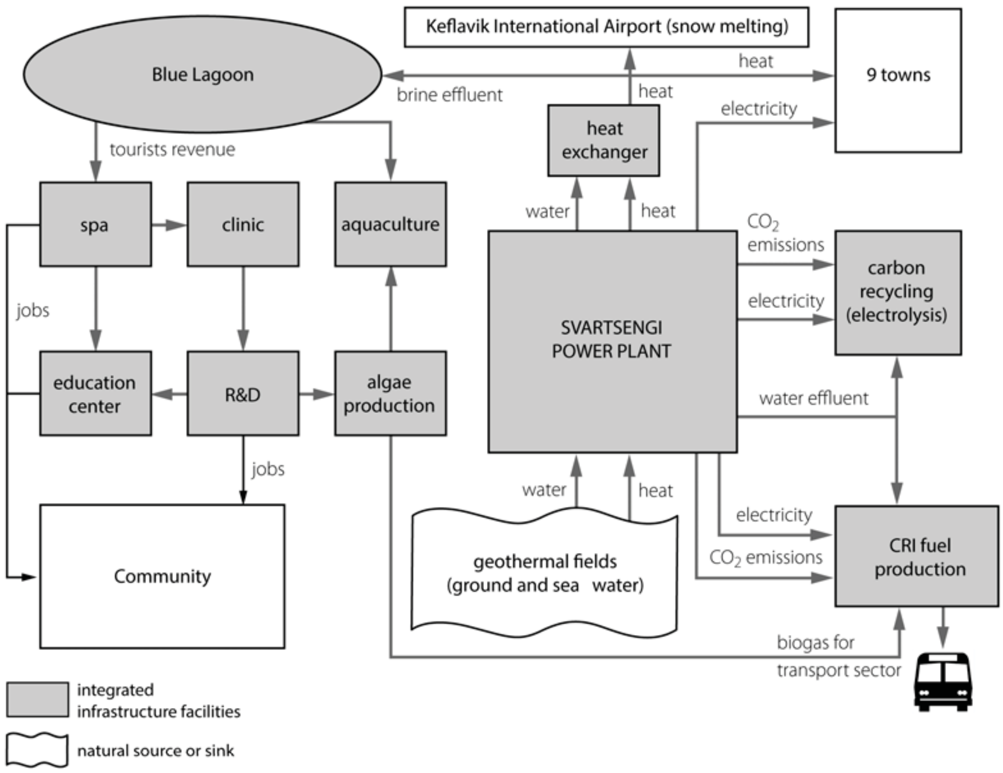


Figure 5. Svartsengi Resource Park, Grindavík, Iceland. (H. Brown, permission Island Press 2014)

Svartsengi's industrial ecology was recently enhanced by the development of micro-algae-for-fuel cultivation in collaborations between Svartsengi, the government of Iceland, and a private Icelandic-America company. Using plant electricity to separate hydrogen from water, hydrogen is combined with the renewable power plant's modest CO_2 emissions to yield 1.5 million liters of a methanol syngas (Tran and Albertsson 2010.) This renewable fuel was introduced into the Icelandic market in 2011, but today also ships to the Netherlands (Valdimarsson 2013). Utilization of geothermal exergy (available energy for beneficial use), synergistic facilities, and the transformation of the plant's CO_2 emissions into a valuable fuel makes the Resource Park an exemplar circular economy.

© ASCE 2014

Reviving an Island Economy on Renewables: Lolland, Denmark's Energy Partnerships

An unusual international collaboration rescued the defunct economy of the former shipping port on the Island of Lolland, replacing it with a vigorous research and development platform and local application of green power, while generating a number of co-benefits (fig. 6). Sponsored in part by the Danish Energy Authority, Baltic Sea Solutions, private industry, a U.S. NGO, and multiple universities, the 2008 creation of Lolland Community Testing Facilities (CTF) and nearby Nakskov Industry and Environment Park integrates several local resources to create a hydrogen-powered community that has restored the local economic base (Magnoni and Bassi 2009).

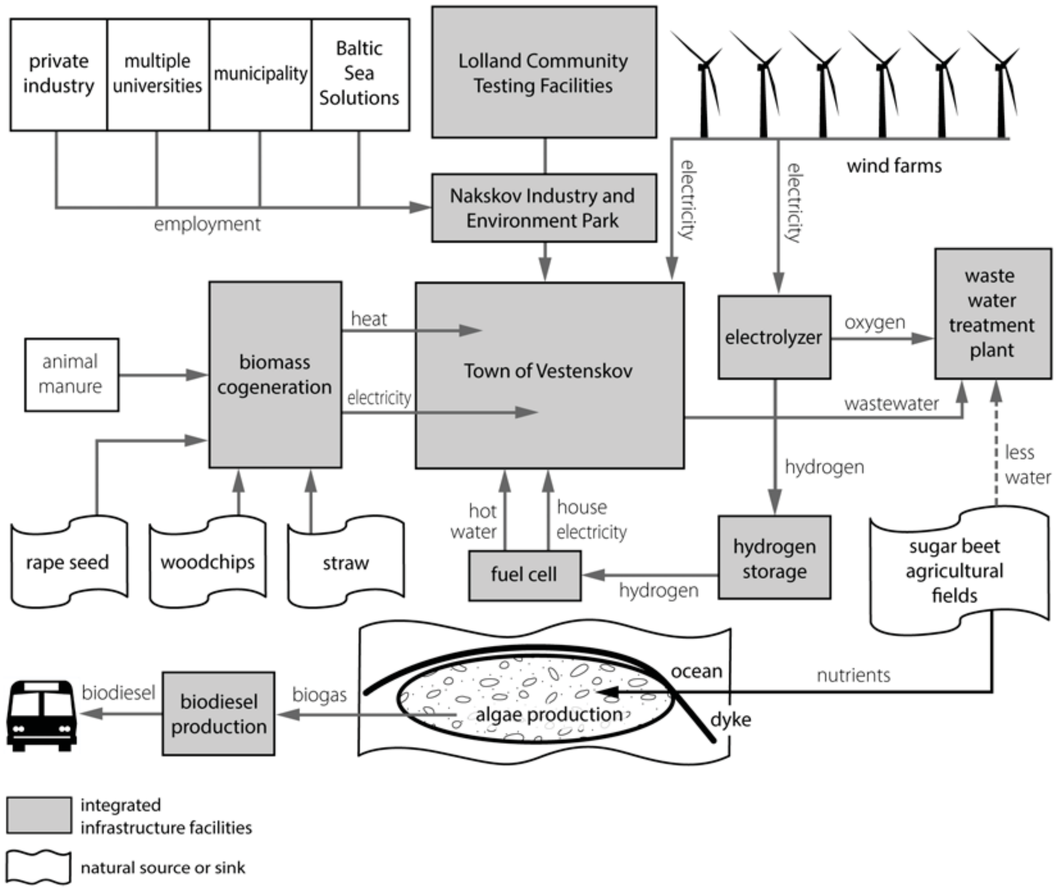


Figure 6. Lolland Hydrogen Community, Lolland, Denmark. (H. Brown, permission Island Press 2014.)

With a planned 50% increase in Lolland's more than 500 land-and sea-based wind turbines that currently produce about 1,000 GWh, the island's excess wind power is put to good use with the construction of an electrolyser plant that splits seawater into hydrogen and oxygen. Hydrogen-powered household fuel cells produce community electricity and hot water, with a combined 90 percent efficiency and zero

© ASCE 2014

carbon emissions (Magnoni 2009). Surplus oxygen is shared with the local wastewater plant to accelerate its treatment processes.

Lolland also relies on district heating from bio-gasification of its wood and agricultural waste and animal manure. Other noteworthy synergies include the production of biodiesel fuel from algae found in the nutrient-rich surplus irrigation water now collected in impoundments formed by new dikes constructed against sea level rise. The cascading of energy and nutrients improves the cost efficiency and ecological performance of Lolland's power, heat, and waste infrastructure while the savings are helping to underwrite ongoing renewable energy investments (Magnononi 2009).

Conclusion

Innovative developers of the above-described infrastructural assets succeeded in improving each asset's overall efficiency and waste reduction while also improving the enterprise's social, economic and environmental performance. By taking a broader, more macroscopic view of the site, capturing underutilized local resources, and integrating natural systems, not only as renewable resources but more importantly as models of integration, infrastructure owner/operators can begin to reconnect across infrastructural sectors, obtaining synergistic benefits from networked energy, water and waste services, and produce more environmentally benign and socially acceptable public works.

REFERENCES

Brick, Karolina "Follow-up of Environmental Impact in Hammarby Sjöstad—Sickla Udde, Sickla Kaj, Lugnet, and Proppen" (report summary, Grontmij AB, March 2008), www.hammarbysjostad.se/ inenglish/pdf/Grontmij%20 Report%20eng.pdf (accessed January 4, 2011).

Brown, Hillary. "Infrastructural Ecologies." *Places: Forum of Design for the Public Realm, Design Observer.* October 2010.

Brown, Hillary. *Next-Generation Infrastructure: principles for post-industrial public works.* Island Press, Washington D.C. 2014.

Chertow. Marian R. ""Uncovering" Industrial Symbiosis."*Journal of Industrial Ecology.* Special Feature on Industrial Symbiosis. 2007:11-30.

Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. *European Commission.* http://ec.europa.eu/environment/waste/landfill_index.htm (accessed 022114).

Domenech, Teresa and Davies, Michael. "Structure and Morphology of Industrial Symbiosis Networks: The Case of Kalundborg," *Procedia Social and Behavioral Sciences* 10 (2011): 79–89.

© ASCE 2014

Frosch, Robert A. "Industrial Ecology: A Philosophical Introduction," Proceedings of the National Academy of Sciences, USA 89 (February1992): 800–803.

Gross, Daniel. "Iceland has Power to Burn." *Newsweek Magazine.* April 5, 2008.
Hyams, D. "Mt. Poso Cogeneration Company Completes Conversion of Power Plant from Coal to 100% Renewable Biofuel Energy." Macpherson Press Release. *Business Wire* February 22, 2012. Also: Conversation with Author, May 6, 2012.

ICLEI Europe. "Case Study: Lille Metropole, France." European Union Regional Policy Case Study, Northumbria University, 2008. http://ec.europa.eu/regional_policy/archive/conferences/urban_rural/doc/caselille.pdf (Accessed February 18, 2014.)

Iveroth, Sofie P. "The Potential of the Infrastructural System of Hammarby Sjöstad in Stockholm,Sweden." Energy Policy 59.716-726 (2013): n. pag. Web. Nov 2013

Jacobsen, Noel B. (2006). Industrial symbiosis in Kalundborg, Denmark: A quantitative assessment of economic and environmental aspects. Journal of Industrial Ecology, 10(1–2), 239–55.

Jacobsen, Noel B. "Industrial Symbiosis in Kalundborg, Denmark: A Qualitative Assessment of Economic & Environmental Aspects. *Journal of Industrial Ecology.* 2006

Lille Métropole Urban Community. "Transfer Centre and Organic Recovery Centre" (General Presentation Lille Metropole Communauté Urbaine, 2009), http://www.biogasmax.co.uk/media/organic_recovery_centre_lille__085752800_1634_26112009.pdf (Accessed February 17, 2014.)

Magnoni, Silvia, and Bassi, Andrea. M. "Creating Synergies from Renewable Energy Investments a Community Success Story from Lolland, Denmark. *Energies.* 2009,2,1151-1169.

Pandit, A., Hyunju, J., Crittenden, J.C., Xu, M. "An infrastructure ecology approach for urban infrastructure sustainability and resiliency." Proceedings, Power Systems Conference and Exposition (PSCE), 2011 IEEE/PES. 1-2.

Ragnarrsson, Arni. "Geothermal Development in Iceland 2005-2009. *Proceedings, World Geothermal Congress,* Bali, Indonesia, 25-29 April, 2010, 1-12.

Stockholm Municipality, 1996a. Hammarby Sjöstad Environmental Program. City planning administration, City of Stockholm, Stockholm.

Stockholm Municipality, 2007. Hammarby Sjöstad – a unique environmentalproject in Stockholm. GlashusEtt, Stockholm.

SYCTOM, Syndicat Intercommunal de Traitement des Ordures Ménagères, "ISSEANE: The Future Issy-les-Moulineaux Household Waste Sorting and Energy

© ASCE 2014

Production Centre," SYCTOM de L'agglomeration Parisienne, 2007, 4, www.syctom-paris.frww.syctom (accessed September 12, 2011).

Tran, K-C, and Albertsson, A. "Utilization of Geothermal Energy and Emissions for Production of Renewable Methanol. *Proceedings, World Geothermal Congress 2010, Bali, Indonesia. 25-29 April.* 1-3.

US Environmental Protection Agency, "Project Profile—University of New Hampshire EcoLine™ Cogeneration System," US EPA Landfill Methane Outreach Program, 2010, http://epa.gov/lmop/projects-candidates/profiles/universityofnewhampshiree.html (accessed February 20, 2014).

Valdimarsson, Omar. "Iceland's Carbon Recycling Sees Rising Demand for Renewable Fuel." *Bloomberg News.* Feb 12, 2013. http//www.bloomberg.com/news/2013-02-12/iceland-s-carbon-recycling-sees-rising-demand-for-renewable-fuel.html. (Accessed February 22, 2014).

Xu, Ming, Weissburg, M., Newell, J.P., Crittenden, J.C. "Developing a Science of Infrastructure Ecology for Sustainable Urban Systems." Environ. Sci. Technol. 2012, 46, 7928□7929

Xu, M., Crittenden, J. C., Chen, Y., Thomas, V., Noonan, D. Desroches, R. Brown, M., French, S. "Gigaton Problems Need Gigaton Solutions." *Environmental Science & Technology.*Vol. 44, No. 11, 2010. 4039-4041

© ASCE 2014

Introducing First Year Engineering Students to Infrastructure Sustainability Rating Systems

Angela R. Bielefeldt[1]

[1]Department of Civil, Environmental, and Architectural Engineering, University of Colorado, 428 UCB, Boulder, CO 80309; PH (303) 492-8433; FAX (303) 492-7317; email: angela.bielefeldt@colorado.edu

ABSTRACT

A sustainability module was included in courses for first-year engineering students majoring in civil, environmental, architectural, and general engineering at the University of Colorado Boulder. The low infrastructure grades in America were used to help motivate students about the importance of sustainable engineering. A homework assignment required students to select a case study from one of the ASCE Infrastructure Report Card areas, and discuss how it did or could target sustainability. A rubric was used to determine if students discussed environmental, social, and economic aspects. The civil, architectural, and general engineering students also explored the Greenroads® Rating System, LEED, or ENVISION™, respectively. Environmental engineering students explored life cycle assessment. At the end of the semester the students increased in their self-efficacy for sustainable engineering knowledge. The paper provides an example of a simple module that helped students achieve knowledge and comprehension of sustainable engineering.

INTRODUCTION

Sustainable infrastructure is important in order to make the best investment of tight funds and realize the full potential of broad societal benefits. In fact, striving for sustainable development has been identified as an ethical imperative for civil engineers since 1996 (ASCE 2012). Therefore, engineering students must be taught about the importance of sustainability and tools to evaluate sustainability.

Within the American Society of Civil Engineers (ASCE) Body of Knowledge (BOK2), sustainability has been identified among twenty-four prerequisite knowledge outcomes for professional licensure (ASCE 2008). For sustainability, it is intended that students graduating with a bachelor's degree have reached the knowledge, comprehension, and application levels of Bloom's taxonomy, with achievement of the analysis level through prelicensure experience. As quoted from the BOK2, this implies that students can:

(1) Define key aspects of sustainability relative to engineering phenomena, society at large, and its dependence on natural resources; and relative to the ethical obligation of the professional engineer.

© ASCE 2014

(2) Explain key properties of sustainability, and their scientific bases, as they pertain to engineered works and services
(3) Apply the principles of sustainability to the design of traditional and emergent engineering systems.

There are also requirements that all ABET accredited engineering programs reach student learning outcomes pertaining to sustainability, but these are somewhat vague. For example, ABET Criterion C outcome (h) requires students have "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context", and "(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" (ABET 2013). However, the "such as" in Criterion C (c) means that students are not required to consider *all* of these design constraints. As such, the ASCE's Civil Engineering Program Criteria Technical Committee (CEPCTC) has proposed to add a sustainability outcome into the ABET program-specific criteria for civil engineering (ASCE 2013).

Educating civil engineers to design sustainable infrastructure is a challenge. Undergraduate curricula are already crowded with educational requirements, and face pressure to decrease the number of credits (Russell et al. 2007; Fridley 2011). Therefore, requiring an entire course on sustainable engineering may be impractical for most undergraduate degree programs. Further, it is unclear that this educational approach would be optimal. Rather, a better approach may be to infuse sustainability into a variety of courses and espouse an engineering design approach of *normalized sustainability* (Cardella et al. 2010). This approach is more in line with *education for sustainability*, which considers students' attitudes and develops students who value sustainability (Glover et al. 2011; Mouchizuki et al. 2010; Wals 2012). It also aligns with requirements to infuse sustainability throughout the engineering curriculum in accredited programs in New Zealand (IPENZ) and through civil engineering curricula in the UK (Joint Board of Moderators 2013).

The goal of this research was to integrate learning modules on sustainability into courses for first year engineering students. These modules introduced students to sustainability definitions and rating systems to evaluate sustainability. The effectiveness of these modules was assessed using rubrics to score homework assignments and/or a survey to evaluate students' motivation toward sustainable engineering.

TARGET COURSES

The author of this paper developed sustainability modules for first-year courses that she taught at the University of Colorado Boulder. These courses were part of the required curriculum for civil, environmental, architectural, and general engineering students. These courses were taught in the first semester (fall) and varied from one to two credits. In each course, a knowledge of sustainability was one among multiple learning objectives for the course. For the civil and architectural engineering courses, the articulated learning goals of the sustainability module were:

1. define sustainability

© ASCE 2014

2. describe the importance of sustainability to engineering
3. identify aspects of sustainability in civil/architectural engineering projects

The years that provide the data for this paper and the sustainability-related learning activities in the modules are summarized in Table 1. In all of these first-year courses the students were presented with definitions of sustainability, sustainable development, and sustainable engineering (Mihelcic et al. 2003; UN 1987). The courses used a "case study" approach to illustrate and discuss sustainability (RAE 2005; Bielefeldt 2011; Bielefeldt 2013). In each course, an appropriate sustainability rating system was introduced to the students. In 2012 the civil and architectural engineering students shared the same course lectures, but had slightly different assignments.

Table 1. Sustainability-related Activities in First-Year Engineering Courses

Target Discipline	Year(s)	In-class	Supporting Assignments
Civil engineering (CE)	2009-2012	2-3 lectures, clicker questions	Homework Design project
General engineering (GenE)	2012	1 class period; lecture + group activity	Homework
Architectural engineering (AE)	2012	3 lectures, clicker questions	Homework Design project
Environmental Engineering (EnvE)	2009-2010	2 lectures, clicker questions	Homework LCA project

The sustainability learning goals complemented the ethics learning goals in these first year courses. Other course activities such as a mini-design project and/or engineering project study reinforced the sustainable engineering elements.

SUSTAINABILITY MODULES

Infrastructure Report Card. The low infrastructure grades in America were used to help motivate students about the importance of sustainable engineering. All of the modules included in-class discussion of the ASCE Infrastructure Report Card grades. The homework assignment required students to select one of the graded areas, summarize the reasons for its grade, and select one of the case studies from the document and discuss how it did/could address each of the three pillars of sustainability. The flexibility in the question allowed the students to choose an infrastructure topic of personal interest.

Sustainability Rating Systems. In each course, a different sustainability rating system or method was highlighted: Greenroads® for CE, LEED for AE, ENVISION™ for GenE, and life cycle assessment (LCA) for EnvE. A brief comparison of some aspects of these rating systems that are similar is shown in Table 2.

© ASCE 2014

Table 2. Examples of Comparable Rating Categories in Different Sustainability Rating Systems

Greenroads®	LEED NC, 2009	ENVISION™	LCA
MR-6 energy efficiency	EA1 optimize energy performance	GR1.1 greenhouse gas emissions	GHG emissions
CA-4 fossil fuel use reduction	EA2 on-site renewable energy	RA2.2 renewable energy	replaced fossil energy
MR-4 recycled materials	MR4 recycled content	RA1.3 recycling	resource use
MR-5 regional materials	MR5 regional materials	RA1.4 regional materials	
CA-7 water use tracking	WE4 water use reduction	RA3.2 water consumption	water consumption
AE-1 safety audit	IEQ5 Indoor chemical & pollutant source control	QL2.1 public health & safety	human toxicity

Greenroads®. In the *Introduction to Civil Engineering* class in Fall 2011 and Fall 2012, the GreenRoads® rating system (Anderson et al. 2011) was introduced to the class. Greenroads® is a points-based system to certify sustainable road and transportation projects (https://www.greenroads.org/). The rating system was introduced in one lecture. Then the GreenRoads® system served as the basis for one of the four required problems on the sustainability homework assignment. Students were individually required to: (a) Classify each of the 11 project requirements (PRs) into which one of the three sustainability pillars each PR is primarily related; (b) select one of the voluntary credits earned by the US 97 Lava Butte project (Scarsella 2010), discuss what was done to earn this credit and how this element contributes to the overall sustainability of the project; and (c) discuss whether or not the student thought that the Lava Butte project should have tried to earn one of the credits that were not achieved but possible, and why it would/would not have been beneficial overall.

LEED. In 2012, the architectural engineering students focused on the Leadership in Energy & Environmental Design (LEED) scoring system developed by the U.S. Green Building Council (2014). One entire 50-minute lecture was devoted to LEED. A newly constructed on-campus dormitory (CU WillVill) that had achieved LEED platinum rating served as a case study for questions worth 55% of the grade on the sustainability homework assignment. This case study was selected because some of the students lived in this dormitory and it was easy for students to visit. However, one disadvantage was that the dormitory was certified under the LEED NC 2.2 system, which was out of date with the current LEED scoring system. The homework requirements were: (a) classify each of the eight pre-requisites into which one of the three sustainability pillars each was primarily related (LEED 2009 for New Construction); (b) select two of the credits earned by the CU WillVill project (each in a different category), discuss what was done to earn this credit, and discuss how this element contributed to the overall sustainability of the project; (c) select one

© ASCE 2014

of the credit categories not achieved for the CU WillVill project, discuss whether or not you think the project should have tried to earn this credit and why it would/would not have been beneficial overall; (d) Using the LEED 3.0 (2009) system, determine if the project would/would not be platinum certified under the newer scoring system.

ENVISION™. In the *Introduction to Engineering* course for general engineering students in fall 2012, some students were enrolled in a 5-week module on civil engineering. Within the civil engineering module, one class period (of five) and one assignment related to sustainability. ENVISION™ (Institute for Sustainable Infrastructure 2014) formed the basis for an in-class team exercise. In self-assembled groups of three to four students, the groups identified five of the fifty-five point categories that primarily represented each of the three pillars of sustainability. They also discussed the variability in the points that could be earned in different categories at the same "level" of sustainability. An individual assignment required the students to discuss how the Envision™ 2.0 Sustainable Infrastructure rating system might apply to civil engineering projects to improve the infrastructure system that the student selected from among the ASCE Infrastructure Report Card areas. Students were instructed to include specific examples that related to each of the three pillars of sustainability and the various point-earning elements in the Envision™ system.

Life Cycle Assessment. The environmental engineering students did not learn about a particular sustainability rating system. Rather, on the sustainability homework assignment they applied the Royal Academy of Engineering's (2005) *Guiding Principles for Sustainable Development* and the *Hannover Principles* (McDonough 1992) to a case study. Then in a separate, follow-on assignment they explored life cycle assessment (LCA) of biofuels. One lecture discussed various biofuels and sustainability-related factors. Then the students were provided with one or more peer-reviewed journal papers that had conducted an LCA of one or more fuels (petroleum-based gasoline or diesel fuel) and/or biofuels. The students were required to compare various quantitative and qualitative indicators from the LCA and justify which fuels seemed the most sustainable overall.

DIRECT ASSESSMENT

Evaluation of the sustainability definitions on the student homework assignments in order to evaluate achievement of the first sustainability learning goal was fairly straight-forward, using a rubric (Table 3). For each of the four desired elements of the sustainability definition, students were awarded either full credit (1 point), half credit (0.5 points for weakly included), or no credit (0 points). This resulted in an overall score of 3.5 to 4 = superior; 2.5 to 3.5 = adequate; or <2.5 weak.

Table 3. Sustainability Definition Scoring Rubric and Example 2010 CE Results

	Long-term	Environmental	Economic	Social	Total	
Full credit	93%	98%	88%	100%	Superior	93%
Half credit	2%	0%	12%	0%	Adequate	7%
No credit	5%	2%	0%	0%	Weak	0%

© ASCE 2014

As part of a homework assignment the students were required to select one of the ASCE Infrastructure Report Card areas, summarize it, and then select a case study from the document and discuss how it did or could target sustainability. Not surprisingly, the most popular topics varied by group (Table 4). Drinking water was among the top three most popular topics for all four groups, perhaps due to its impact on everyone's daily lives and concerns about safety. Energy was among the three most popular topics for environmental and architectural engineering. Many of the students indicated that they selected a particular topic due to future career interests.

Table 4. Infrastructure Topics Self-Selected By Students

Topic	Civil (n=217)	Environmental (n=146)	Architectural (n=31)	General (n=114)
Drinking water	12%	43%	23%	24%
Energy	4%	34%	13%	4%
Bridges	22%	0%	13%	7%
Dams	23%	0%	6%	4%
Roads	9%	0%	6%	21%
Aviation	4%	0%	3%	17%
Levees	12%	0%	3%	4%
Hazardous waste	1%	10%	0%	3%
Solid Waste	1%	7%	10%	0%
Schools	1%	0%	23%	4%

A rubric was used to determine if students discussed environmental, social, and economic aspects in the infrastructure case studies (Table 5). Students did very well, on average earning 93% on economic and social elements, and 83% on environmental elements.

Table 5. Rubric for sustainability discussion of infrastructure case studies

Dimension	No evidence 0 pts	Weak discussion 1-2 pts	Good example provided 3 pts
Environmental	Lacked any mention of environmental impacts	Mentioned environmental elements in discussion but did not give specific examples of how case study considered environmental impacts	Good examples of efforts to minimize negative environmental impacts, such as decreased air pollution, material recycling, waste minimization, minimized energy consumption, etc.
Economic	No mention of cost, local economic benefits, etc.	Mentioned cost or economics but did not show how case study was a sustainable example	Discussed how innovations saved taxpayer money, provided jobs, etc.
Social	Lacked any mention of social benefits	Mentioned social benefit but did not give a concrete example that pertained to the case study	Gave examples that community input considered, contributed in a positive way to the community, considered social equity, etc.

Common themes associated with each sustainability pillar were determined. Common themes for social impacts were safety, time savings/convenience, and

© ASCE 2014

aesthetics. For environmental impacts, pollution, conversing natural resources, waste, and ecosystem benefits were most often discussed. For economics, common themes were long-term cost savings and jobs.

Greenroads®. Most of the students were successful in selecting rational classifications for the 11 Project Requirements (PRs) in the Greenroads® rating system; the majority were primarily environmental impacts (Table 6). For voluntary credits that were earned, most students (38%) elected to discuss credits in the environment & water (EW) category, with the site vegetation credit (EW-5) being the single most popular. The materials & resources (MR) category was also popular (24%), while fewer students discussed credits in the access & equity (AE; 11%), construction activities (CA; 5%), and pavement technologies (PT; 3%) categories. Most of the students (87%) discussed environmental benefits of these activities, with social (33%) and economic (17%) benefits described less frequently. Unfortunately, 19% of the students erroneously discussed one of the PRs instead of a voluntary credit. For the discussion of voluntary credits not earned, the most popular topics were EW (24%), CA (18%), PT (13%), MR (5%), and AE (5%); again, a significant number of the students (34%) erroneously discussed a PR instead of a voluntary credit. The reason that the majority of the students discussed EW elements may have been because that was the first category of voluntary credits listed on the scoring sheet.

Table 6. Primary Sustainability Pillar of the Greenroads® Project Requirements (PRs) (*italics, strongly related to multiple pillars*)

Economic	Environmental	Social
PR-2 Lifecycle cost analysis	PR-1 Environmental review process	*PR-4 Quality control plan*
PR-4 Quality control plan	PR-3 Lifecycle inventory	PR-5 Noise mitigation plan
PR-9 Pavement mgmt. system	PR-6 Waste management plan	PR-11 Education outreach
PR-10 Site maintenance plan	PR-7 Pollution prevention plan	*PR-9 Pavement management system*
	PR-8 Low impact development	

LEED. The LEED system seemed to be generally understood by the architectural engineering students. Most students successfully identified a primary sustainability pillar into which each of the pre-requisite categories could be allocated. The students were able to use the case study documentation to identify and explain two categories where the dormitory earned points, with the energy and atmosphere (EA; particularly on-site renewable), water efficiency (WE; particularly water use reduction), and sustainable sites (SS; particularly public transit access) categories being most popular (28%, 28%, and 22%, respectively). The extent to which the students described the various environmental, economic, and social benefits of earning the points varied widely. The students were also able to select one category where points were not earned and discuss why/why not they thought the project should have tried to earn those points; most students discussed SS or materials & resources (MR) topics (32% and 21%, respectively). However, for the final question most students did not try to walk through the newer LEED scoring system to determine if the building would have made platinum rating under the newer 3.0

© ASCE 2014

system. Some erroneously took the 52 points from the old system and just put into the new point category ranges, not taking into account that the maximum number of points available changed drastically. Some erroneously calculated the percentage of the total points earned and assumed that percentage stayed the same, not taking into account that the point distribution between categories changed.

ENVISION™. The general engineering students demonstrated good understanding of the ENVISION™ system on the team portion of the assignment, earning an average of 88% of those points. The most common errors were mischaracterization of some of the ENVISION™ categories as primarily economic. Specifically, renewable energy, stakeholder involvement, regional materials, and recycled materials were frequently mischaracterized as being primarily economic related factors. Applying the ENVISION™ rating categories to the infrastructure case studies was variably successful. Twenty-one percent of the students discussed sustainability in very general terms rather than linking to the specific credit categories in ENVISION™. The majority of the students selected three specific categories for discussion, although one student cited nine different areas that applied to her case study. The most popular ENVISION™ categories cited by the students included QL2.1 public health and safety (55% of the students), QL1.1 improve community quality of life (24%), LD3.1 plan for long term monitoring and maintenance (21%), LD3.3 extend useful life (18%), and RA3.1 protect freshwater availability (18%). Some students were able to discuss how a single point category yielded environmental, societal, and economic benefits.

LCA. Teaching sustainable engineering without the aid of a sustainability rating system seemed less effective for achieving student understanding. On the otherwise similar sustainability homework assignment, EnvE students averaged 89% compared to 92-94% for CE and AE students. The life cycle assessment seemed very difficult for many of the first year students to grasp; the average score of 79% on this assignment was the lowest of any of the seven assignments during the semester. The majority of the categories for LCA selected by the students focused on environmental effects, seeming to result in a less balanced approach to sustainable engineering with due consideration of societal and economic factors. The lack of consensus in the engineering community of what categories are included in a LCA supports the difficulty with trying to teach students about sustainability using this approach.

INDIRECT ASSESSMENT

The extent to which students were confident of their knowledge related to sustainable engineering (SE) (self-efficacy) was evaluated using a survey (McCormick et al. 2013). The questions asked students to “rate your degree of confidence” on 13 items using an 11-point Likert scale from 0 = no confidence; 50 = moderately confident; 100 = very confident. Three items each mapped to the environmental, social, and economic pillars of sustainability, while four items mapped to integrated sustainability areas. Examples of the items were: *identify the environmental elements of an engineering project*; *understand the social risks*

© ASCE 2014

associated with engineering projects; and *recognize the social and economic impacts in engineering design.* Results are summarized in Table 7. At the beginning of the semester before the sustainability module, individual students varied widely in these elements (shown in the "all" row of Table 7). At the end of semester the students increased in their self-efficacy for sustainable engineering and its sub-elements. There were larger gains for the majors that experienced a sustainability module that included one of the sustainable engineering rating systems, as compared to the environmental engineers whose sustainability module included LCA.

Table 7. Sustainable Engineering Self-Efficacy, ***averages italicized***

	n		Overall		Environment		Society		Economics		Interrelated	
			SE Self-Efficacy (0 to 100 Likert scale)									
All, minimum-maximum	136		13-95		3-93		3-100		7-100		20-98	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
Environmental, 2010	32	25	*53*	*61*	*54*	*62*	*54*	*62*	*48*	*57*	*54*	*63*
Civil, 2010	24	12	*54*	*67*	*50*	*63*	*54*	*68*	*53*	*65*	*58*	*72*
Civil, 2012	14	7	*48*	*67*	*43*	*70*	*46*	*70*	*53*	*63*	*49*	*68*
Architectural, 2012	11	11	*48*	*67*	*44*	*66*	*48*	*68*	*47*	*67*	*52*	*66*

The extent to which students valued sustainability (value), participated in sustainability-related activities (affect), or had negative feelings toward sustainability (negative) were evaluated using a survey based on Expectancy Value Theory (McCormick et al. 2013). Students responded to 22 items using a six-point Likert scale (0 = strongly disagree; 5 = strongly agree). An example of a question that corresponded to each of these three constructs are: *It is important for me to learn how engineers can make the world more sustainable* (value); *I am (or would like to be) enrolled in a sustainable engineering course* (affect); *In engineering design, assessment of the potential impacts on economy, environment, and society is not important* (negative). Results are summarized in Table 8. To explore potential differences between majors and pre-post scores, two-tailed heteroscedastic t-tests were conducted; statistical differences were inferred when p was less than 0.05.

Table 8. Sustainable Engineering Motivation Survey Results, ***averages italicized***

Course, year	n		Affect		Value		Negative	
			0 to 5 Likert					
	pre	post	pre	post	pre	post	pre	post
All, minimum-maximum	81	55	1.1-5.0	1.4-5.0	2.4-5.0	2.6-5.0	0.0-4.5	0.0-5.0
Environmental, 2010	32	25	*3.7*	*3.8*	*4.2*	*4.3*	*1.0*	*1.5*
Civil, 2010	24	12	*2.9*	*3.2*	*4.2*	*4.3*	*1.2*	*2.1*
Civil, 2012	14	7	*2.5*	*3.1*	*4.2*	*3.8*	*0.8*	*1.6*
Architectural, 2012	11	11	*2.7*	*3.0*	*3.8*	*4.0*	*1.5*	*1.8*

Not surprisingly, environmental engineering students had the most positive sustainable engineering affect at the beginning of the semester, compared to the other disciplines. Civil engineering students increased in sustainable engineering affect at the end of the semester. However, negative perceptions about sustainable

© ASCE 2014

engineering also increased among civil engineering students.

Student Comments. The on-campus LEED building case study seemed to make civil/architectural engineering and sustainability tangible, and was envisioned by students in their future careers. Example quotes from students' final reflective essays at the end of the semester that illustrate this idea are provided in italics below:

Before this class, I didn't understand how important "sustainability" is and how it is present in every aspect of every project. I thought that the LEED rating system was a little extensive at first, but soon realized that it was necessary and that we should value "green" engineering.

Learning about all of the ways that sustainability can be incorporated into construction helped strengthen my interest. I am very interested in any way that I can improve the environmental situation as a civil engineer.

Thanks to lectures like that on Green Roads and LEED I found that design and science although great is not all there is. LEED in particular showed that the human/public element of large projects like buildings often outweigh the natural and physical forces that constrict design.

Aspects of Civil Engineering that appeal to me are the designing and building of structures, sustainability requirements, and overall results of projects. I am looking forward to being able to create a structure that will be built and used by people. I am also looking forward to building sustainable structures. I look forward to learning more about these requirements and trying to build structures that meet high LEED standards.

As strange as it sounds, the most interesting aspect of architectural engineering that appeals to me would have to be the idea of creating a building that meets LEEDS certification. I would love to be able to start out from scratch creating designs and turning them into real projects deemed sustainable and practical.

For the environmental engineering students, feedback on the LCA project were both positive and negative. A few example quotes from the end-of-semester reflective essays of the students are given in italics below.

The LCA assignments showed the complexity of environmental engineering and sustainability. This is a daunting task, which makes me hesitant that I won't be able to take on all the aspects of each project.

Assignments, like the LCA, were valuable in teaching us how many factors must be taken into account when considering a new technology or development. It also made us aware of a tool used by professional engineers.

The LCA projects… made things worse for me. Again, it was something completely technical that I couldn't even understand on my own.

I enjoyed the majority of the assignments…. My favorite was the group LCA project we completed because it seemed to be directly applicable to what actual environmental engineers do.

The contrast between largely positive (or absent) comments on the sustainability rating systems by CE and AE students compared to the mixture of negative and positive comments on LCA by EnvE students points to the benefits of a more defined method to "score" sustainability. This scoring approach seemed to give

© ASCE 2014

the students more tangible ideas about the attributes of engineering projects that contribute to sustainability.

SUMMARY AND CONCLUSIONS

This paper provided an example of simple modules that helped students reach the knowledge and comprehension levels of sustainability with respect to Bloom's taxonomy, as articulated in the ASCE Body of Knowledge (BOK2). The sustainability rating systems were easier for students to understand than lists of sustainability principles or life cycle assessment. The students were able to demonstrate an understanding of sustainability through a case study analysis in the context of the rating system. In the future, it is likely that the civil engineering class will switch from using the Greenroads® rating system to ENVISION™. This will allow a wider range of case studies to be used, rather than just transportation infrastructure. This is particularly important since at CU transportation is not one of the five focus areas available to our civil engineering students. ENVISION™ could also be applied in the environmental engineering course. The combination of case studies with the sustainability rating systems seems to be an effective method to increase students' knowledge of sustainable engineering.

ACKNOWLEDGEMENTS

This material is partially based upon work supported by the National Science Foundation under Grant No. #0935209. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

ABET. (2013). *Criteria for Accrediting Engineering Programs. Effective for Reviews During the 2014-2015 Accreditation Cycle*. ABET Engineering Accreditation Commission. Oct. 26, 2013. Baltimore, MD.

American Society of Civil Engineers. (2012). *The ASCE Code of Ethics: Principles, Study and Application.* http://www.asce.org/uploadedFiles/Ethics/Principles-Study-Application/ASCE-Code-Of-Ethics-2012-low-res.pdf (July 1, 2014)

American Society of Civil Engineers. (2008). *Civil Engineering Body of Knowledge for the 21st Century. Preparing the Civil Engineer for the Future.* Second Edition. ASCE. Reston, VA.

American Society of Civil Engineers. (2009). *Report Card for America's Infrastructure*. http://www.asce.org/reportcard (July 1, 2012).

American Society of Civil Engineers (ASCE) Civil Engineering Program Criteria Task Committee (CEPCTC). (2013). *Proposed Civil Engineering Program Criteria, Effective for the 20156-2017 Accreditation Cycle*. Version 20 Dec. 2013. Sent as an attached file to Department Heads Listserve, 21 Dec. 2013.

Anderson, J., Weiland, C., and Muench, S., Eds. (2011). *Greenroads Manual.* V. 1.5. http://www.greenroads.us/ (August 12, 2011).

Bielefeldt, A.R. (2011). "Incorporating a sustainability module into first-year courses

© ASCE 2014

for civil and environmental engineering students." *J. Prof. Issues Eng. Educ. Pract.* 137, 78–85.

Bielefeldt, A.R. (2013). "Pedagogies to achieve sustainability learning outcomes in civil and environmental engineering students." *Sustainability*, 5, 4479-4501.

Cardella, M.E., Hoffman, S.R., Ohland, M.W., Pawley, A.L. (2010). "Sustaining sustainable design through 'normalized sustainability' in a first-year engineering course." *Int. J. Eng. Educ.*, 26 (2), 366-377.

Fridley, K.J. (2011). "Today's BSCE: A Survey of Credit Hour Requirements." *American Society for Engineering Education (ASEE) Annual Conference & Exposition Proceedings*, ASEE, Washington D.C.

Glover, A., Peters, C., Haslett, S.K. (2011). "Education for sustainable development and global citizenship: An evaluation of the validity of the STAUNCH auditing tool." *Int. J. Sustain. High. Educ.*, 12 125–144.

Institute for Sustainable Infrastructure. (2014). *Envision^{TM} Sustainable Infrastructure Rating System.* http://www.sustainableinfrastructure.org/rating/index.cfm (Feb. 28, 2014).

Institution of Professional Engineers New Zealand (IPENZ). Requirements for Initial Academic Education for Professional Engineers. http://www.ipenz.org.nz/ IPENZ/ Forms/ pdfs/Initial_Academic_Policy_Prof_Eng.pdf (Aug. 8, 2013).

Joint Board of Moderators. Annex C—Sustainability in Degree Programmes. http://www.jbm.org.uk/uploads/JBM123_AnnexCSustainability.doc2013.pdf (Aug. 8, 2013).

McCormick, M., Bielefeldt, A.R., Swan, C.W., Paterson, K.G. (2014). "Assessing students' motivation to engage in sustainable engineering." *Int. J. Sustain. High. Educ.* In press.

McDonough, W. and Partners. (1992). "The Hannover Principles: Design for Sustainability." Prepared for EXPO 2000, Hannover, Germany.

Mihelcic, J.R., Crittenden, J.C., Small, M.J., Shonnard, D.R., Hokanson, D.R., Zhang, Q., Chen, H., Sorby, S.A., James, V.U., Sutherland, J.W., Schnoor, J.L. (2003). "Sustainability science and engineering: the emergence of a new metadiscipline." *Environ. Sci. Technol.*, 37, 5314-5324.

Mochizuki, Y., and Fadeeva, Z. (2010). "Competences for sustainable development and sustainability: Significance and challenges for ESD." *Int. J. Sustain. High. Educ.*, 11, 391–403.

Royal Academy of Engineering. (2005). *Engineering for Sustainable Development: Guiding Principles.* R. Dodds and R. Venables, Eds. RAE, London, UK.

Russell, J., Golloway, G., Lenox, T., O'Brien, J. (2007). "ASCE Policy 465? The means for realizing the aspirational visions of civil engineering in 2025." *American Society for Engineering Education (ASEE) Annual Conference & Exposition Proceedings,* ASEE, Washington D.C.

Scarsella, M. (2010). *US 97: Lava Butte—S. Century Drive Section*; Greenroads Pilot Project Report Version 1.0.1; Oregon Department of Transportation: Salem OR.

U.S. Green Building Council. (2014). LEED. http://www.usgbc.org/leed (Feb. 28, 2014).

© ASCE 2014

UN World Commission on Environment and Development. (1987). *Our Common Future, Brundtland Report*. Oxford University Press, Oxford, UK.

Wals, A.E.J. (2012). *Shaping the Education of Tomorrow: 2012 Full-length Report on the UN Decade for Education for Sustainable Development*; United National Educational, Scientific and Cultural Organization (UNESCO): Paris, France.

© ASCE 2014

Energy and Water Management for Industrial Users

Todd M. Musterait, P.E., ENV SP, LEED Green Associate[1], James R. Jensen, P.E.[2]

[1]WSP, 2360 Sweet Home Road, Suite 3, Amherst, NY 14228; PH (716) 691-5232; email: todd.musterait@wspgroup.com (formerly with HDR)

[2]HDR, 1200 MacArthur Blvd., Mahwah, NJ 07430-2322; PH (201) 469-0560; email: jim.jensen@hdrinc.com

ABSTRACT

The linkage between energy, water, wastewater and greenhouse gas (GHG) emissions has become an important topic for industrial manufacturing operations. Productivity initiatives across the industrial manufacturing sector are creating demand for energy and water programs that reduce operating costs and provide environmental benefits. Stakeholders are able to elevate the need for energy, water, and wastewater programs through various business drivers. Defining leading and lagging metrics are an important component towards successfully implementing an energy and water management program. Energy and water optimization opportunities identified in facilities may be more successful when evaluated outside the structure of a traditional energy-water nexus approach. Organizations are now considering the interaction of water optimization through reduction and reuse, energy consumption reduction and demand management, downstream waste management practices, and GHG emissions as an integrated approach.

This paper presents perspectives on energy and water management program development and assessment. This includes strategic planning with a bottom up and top down approach for water and energy consumption reduction schemes, management of downstream waste and wastewater, and associated GHG impacts.

Energy and Water Management – The New Corporate Productivity Initiative

"Selling" the energy and water management program to senior leadership as "doing the right thing" can take many forms. For companies that are followers in sustainability, ensuring the program is categorized as a productivity initiative provides greater opportunities to drive the environmental benefits that result from implementing energy and water projects. There has been a recent trend towards categorizing energy and water management in an industrial manufacturing setting as a means to remove cost from operations while improving productivity as a "bottom line" initiative. As organizations look to offset the headwinds of inflationary costs including labor, transportation, distribution, and commodities; productivity initiatives are driving out costs, improving margins, and supporting a culture of "better, cheaper, faster". This is the productivity mindset that corporations have embedded into the culture of their organizations.

Escalating energy, water, wastewater, and waste management costs and market corrections continue to drive increased focus and opportunities to do what's good for business and good for the environment, as businesses look for both cost savings and environmental benefits. Industrial manufacturers continue to address sustainability inquiries from their key customers in three target areas including energy, water/wastewater, and solid waste. In order to stay in front of these inquires while driving operational improvements and cost reduction, energy and water management has evolved into a key productivity driver. Typically, companies look to this program as a means to improve environmental wastewater compliance and identify energy and water projects to reduce operating costs. Senior leadership is more agreeable to pursuing a comprehensive strategy based on energy and water success stories and the potential for additional savings throughout a corporation's manufacturing network.

Many organizations are in a development phase driven by environmental compliance and regulations with no consistent corporate wide plan or model (Figure 1). They are also assessing and determining customer requirements around implementation of energy and water initiatives with linkage to sustainability. This poses significant risk to their business if energy and water optimization is expected as a key supplier. Increasing numbers of customers are requiring the completion of annual sustainability questionnaires. The results are scored and suppliers are ranked according to responses. Energy, water, wastewater, and waste management have become table stakes of these inquires.

Over the past several years, the types of questions/requests have evolved from anecdotal success stories to specific, detailed metrics about processes and finished goods. This includes: formal identification and documentation of sustainability goals and targets, tracking and reporting on progress, steps being taken to lower energy, water, and carbon used in operations, packaging materials management, and waste reduction measures.

In responding to customer inquiries, organizations attempt to balance transparency with confidentiality. The level of detail shared with their end customers must be aligned with the information that leadership teams are willing to disclose to customers. Being connected with an organizations sales force is another avenue to understand their customer pressures and requirements. Sales associates keep organizations in the loop on customer expectations so they can adjust their strategy accordingly to remain "leaders or fast followers".

For many industrial manufacturers, operating facilities need to drive improvements towards environmental stewardship in the communities that they manufacture their products. The most common area for improvement falls into

© ASCE 2014

energy and water conservation, wastewater management, and solid waste management. There are a number of items that demonstrate the need for an energy and water management strategy in order for an organization to remain competitive in the market place. Some perspectives include:

- Many companies are in "survival" mode. Sustainability initiatives at the forefront are those that deliver substantial cost savings.
- Most consumers are not willing to pay a premium for "green" products. Offering products and packaging that are good for the environment and do not increase manufacturing costs is a competitive advantage.
- Reducing energy consumption has been a key focus area, as companies search for ways to reduce operating expenses. Energy efficiency reduces GHG emissions and has a significant impact to the bottom line.
- Globally, water (both quality and quantity) has become a bigger issue than energy for many organizations.
- Future climate change regulations may impact the regulation of water usage, carbon emissions, products composition, labeling, and performance reporting.
- Translating energy savings to GHG emissions helps internal and external audiences understand the environmental impact of corporate initiatives. Carbon calculators and other tools help tell the story.

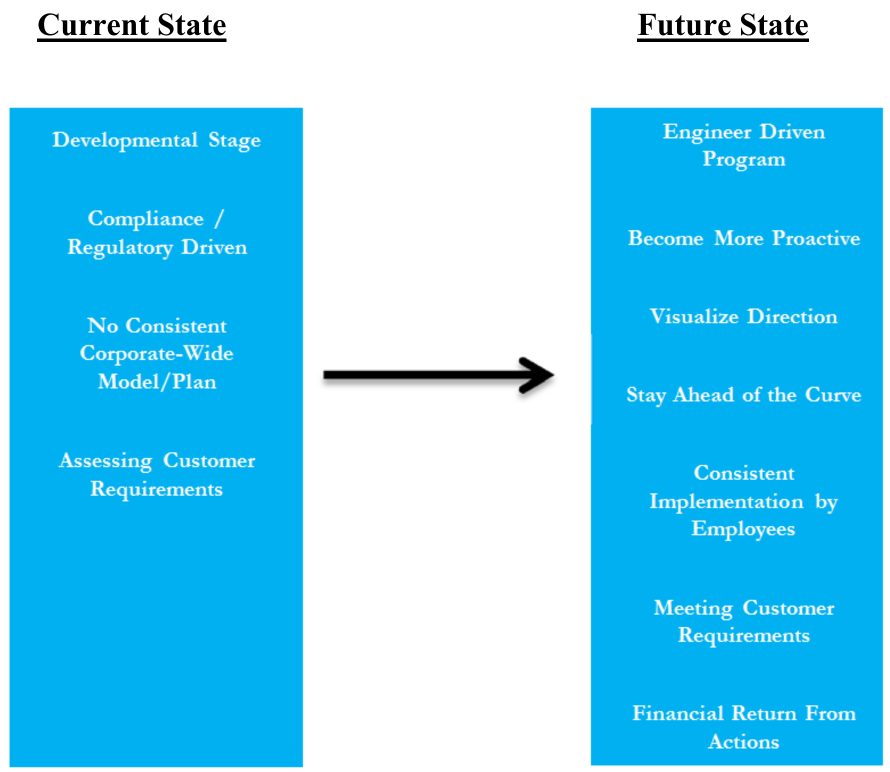


Figure 1. Typical Corporate Energy and Water Management Program

Where Does Energy and Water Management Fit?

As energy and water management becomes a key table stake for successful business operations and environmental benefits, determining where this program fits within an organization is the next topic for discussion. Organizations typically place this program in a corporate environmental department, operations, sustainability leadership team, or locally at the manufacturing facility. Depending upon where this program is funded and resourced dictates the direction based on business priorities. Figure 2 illustrates the connectivity between energy and water management with other organizational change management and systems implementation partnerships. It is important to note that integration of energy and water management with other priority programs within an organization are not solely within one department (e.g., operations, quality, research and development, customer service). There is a connectivity and partnership of programs within an organization that makes them successful over the long term. Energy and water management has become a new and integral part of the entire organizational strategic business structure.

Organizations have mandates and performance requirements they must meet every day to be successful. Products must be delivered pursuant to production schedules, employees and the product are safe, quality standards are achieved, and budgetary requirements are met. Capital, leadership, talent, employee engagement, and established internal department/program partnerships are enablers that improve performance. Energy and water management drives the productivity mindset by improving performance and reducing costs.

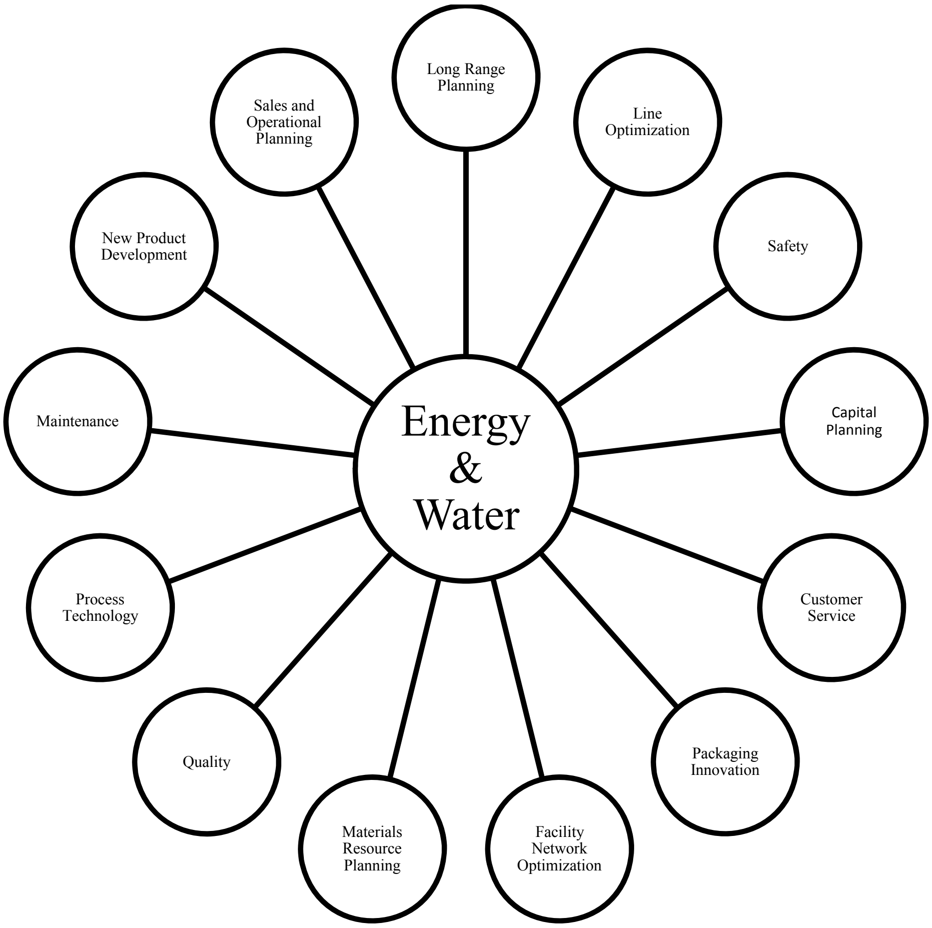


Figure 2. Energy and Water Partnership

Typical Energy and Water Management Program Elements

Successful elements of an energy and water management program include facility assessment/audits, energy and environmental management systems, and consumption/demand management (Figure 3). The focus is on identifying and executing energy, water, wastewater, and waste management projects as quick wins and key sustainability building blocks. Baseline awareness is the first step towards establishing a sustainable energy and water management program. This is followed by facility site energy and water assessments, project identification and execution, and continuous improvement. Figure 4 illustrates a facility implementation process flow.

© ASCE 2014

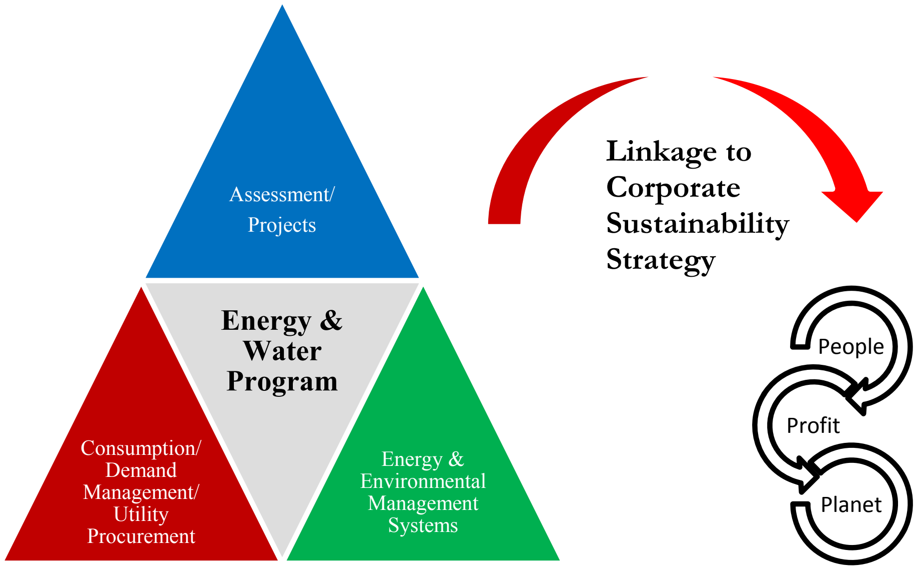


Figure 3. Energy and Water Management Program Elements

Key components of an energy and water management program include establishing goals and key performance indicators (KPIs), utilizing facility assessments, identifying required resources, tracking dashboard applications, program resources, reviewing and identifying utility procurement opportunities at a local facility level, and required tools to execute the strategy. The second level of categories under the primary level will have a plan/strategy and associated document for implementation upon initiating the energy and water management strategy. For example, an energy management system would be launched with individual strategy plans tied to the overall energy and water management strategy. These are descriptive and provide planning to implement those components. Two parallel paths can be implemented to include the necessary systems (tools such as an energy management system) and performing plant assessments, project identification and execution.

© ASCE 2014

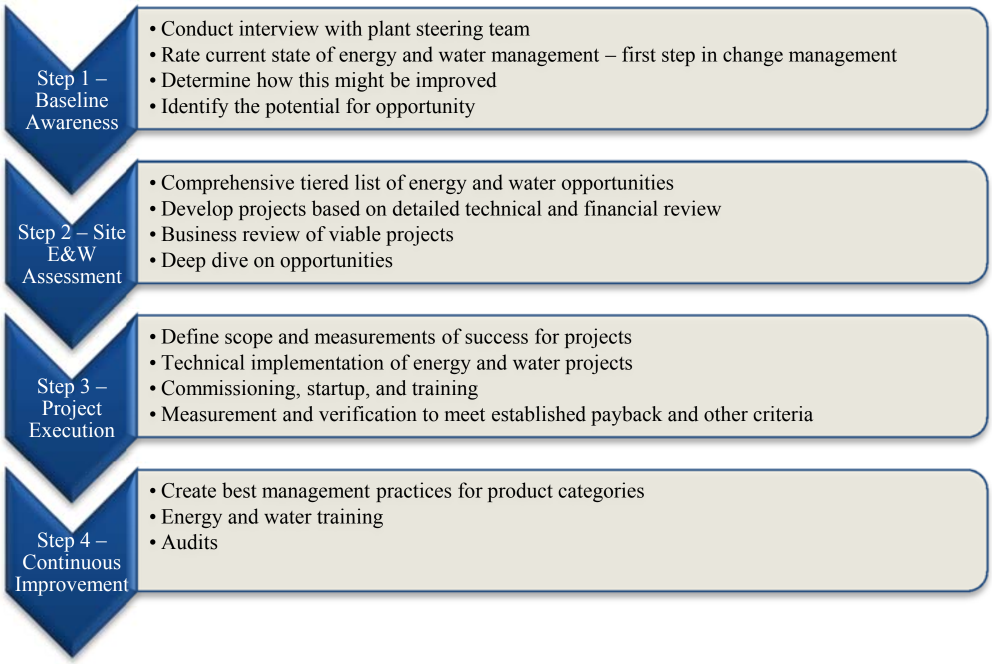


Figure 4. Energy and Water Management Facility Implementation Process Flow

System tools are typically phased into a network of facilities over time. While integration is being conducted, facilities without these systems will need to continue to use existing methods for transferring utility information from invoices to a database located at the facility or corporate operations. These tools allow for automatic generation of KPIs, metrics/targets, and real time data to provide validation of energy/water savings for each project executed. This is important when entering into performance guarantee contracts with vendors for these types of projects. It also provides real time data that facility personnel can review and discuss daily, weekly, and monthly.

For the energy management portion of the strategy, there are three components that when operated in series drive energy improvements and lower operational costs. These include utility rate procurement, demand management, and consumption reduction. Energy project identification and execution will lower facility utility consumption. Managing manufacturing processes with off-peak energy demand and cost structure will lower facility utility demand. These coupled with establishing the appropriate utility rate structure (e.g., time-of-use with variable cost throughout the day, seasonal demand – monthly seasonal flat rate) create the most appropriate energy management structure for each facility.

The United States Environmental Protection Agency (EPA) ENERGY STAR® program for industrial energy management is an excellent resource for the development and maintenance of an energy management program (United States

© ASCE 2014

Environmental Protection Agency, ENERGY STAR®, Washington, D.C.). This program focuses on a variety of industries including cement manufacturing, corn refining, dairy processing, food processing, glass manufacturing, iron and steel manufacturing, metal casting, motor vehicle manufacturing, petrochemical manufacturing, petroleum refining, pharmaceutical manufacturing, printing, pulp and paper manufacturing, and ready mix concrete manufacturing. ENERGY STAR® has developed industry specific energy performance indicator tools to assess a facilities energy usage relative to industry standards. Energy guides such as "Energy Efficiency Improvement and Cost Saving Opportunities for the Baking Industry, An ENERGY STAR® Guide for Plant and Energy Managers" are a great resource for establishing an energy and water management program (Mansanet, Therkelsen, and Worrell, December 2012). Other programs such as the U.S. Green Building Council Leadership in Energy & Environmental Design (LEED®) rating systems and the Institute for Sustainable Infrastructure (ISI) Envision™ Sustainable Infrastructure Rating System are other key components to the development of a successful program. These programs are particularly important during the conceptual design, layout, and construction phases of new industrial manufacturing facilities. Energy and water management infrastructure can be built into the business case for those network optimization projects at the front end loading phase.

Global Perspective

An important component of the energy/water discussion centers on global perspectives. Opportunities are developing for water/wastewater reuse and energy efficiency projects globally that may not meet the return on investment (ROI) thresholds established in the United States. Different challenges exist globally for industrial energy and water management program development and implementation, including resources, governance, financial investment, and culture. There are many areas of the world where water resources are scarce and it is rapidly becoming a challenge to obtain water rights for manufacturing operations. At these locations, water reuse and wastewater treatment for facility reuse have become essential to plant operations. While these types of projects may be more common in these geographical areas, similar projects in the United States would require stakeholder commitment and/or merging a higher ROI water project with an energy efficiency project. This is one of the many challenges when examining the intersection of energy and water to reduce consumption and meet financial thresholds and productivity initiatives.

SUMMARY

The linkage between business drivers, financial considerations, environmental benefits, and employee engagement are critical to the successful development and implementation of an energy and water management program. The lynchpin of a successful plan is categorizing the program as a productivity initiative for the organization. This allows connectivity between departments, initiatives, programs, and organizational mandates.

© ASCE 2014

REFERENCES

Masanet, E., Therkelsen, P., and Worrell, E. (2012). *Energy Efficiency Improvement and Cost Saving Opportunities for the Baking Industry An ENERGY STAR® Guide for Plant and Energy Managers*, Ernest Orlando Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division.

United States Environmental Protection Agency, ENERGY STAR® program, Washington, D.C.

© ASCE 2014

Utilizing a unit commitment and dispatch model to temporally resolve water use data in the Western United States' power sector

Kelly T. Sanders[1]
[1]Sonny Astani Department of Civil and Environmental Engineering, University of Southern California, 3620 S. Vermont Avenue, Los Angeles, CA 90089-2531; ktsanders@usc.edu

Abstract

The power sector is responsible for approximately one-half of the United States' annual water withdrawals and approximately 3% of its annual water consumption. The majority of this water is devoted to cooling thermoelectric power plants by means of once-through or recirculating cooled systems. Despite the large water requirements of the power sector, water conservation strategies are typically concentrated in the urban and agricultural sectors. Although national agencies such as the United States Geological Survey and the Energy Information Administration do publish data regarding the water use requirements of power plants, these data are often incomplete, inaccurate, and are published infrequently. Consequently, data resolving the temporal variability of water use by the power sector are largely non-existent, making conservation strategies difficult to construct.

This analysis utilizes a unit commitment and dispatch (UC&D) model to estimate water requirements of approximately 3,600 power plants in the Western Electricity Coordinating Council in the year 2020. The UC&D model used here computed generation, water consumption, and water withdrawal rates for 8,760 hourly timesteps for the projected load and generation fleet in 2020. Results suggest that the grid will become increasingly water-lean in the future, but will still require 3,600 billion gallons per year in 2020, of which, 7% will be consumed. The results of this study are important for developing effective water conservation strategies through the electric power grid by considering the temporal and spatial aspects of the water supply and the water needs of the grid.

Introduction

Traditional water conservation strategies in the United States (US) tend to focus on water use within the public water supply and the agricultural sector, which represented 13% and 37% of national freshwater water withdrawals in 2005.[1] Although the electric power sector utilized approximately 41% of the US water withdrawals in that year, it has not historically been a large target for strategic conservation schemes.[1] Regardless of these national statistics, water is a locally constrained resource that is typically not economical for large distance transport. Thus, to evaluate whether the power sector might be a strategic area for future water conservation targets, it is important to disaggregate the spatial and temporal distribution patterns of this water use. Since these data are not available at the electric generation unit (EGU) level across small time intervals, this manuscript aims to fill that gap. The major goal of this work is to temporally disaggregate the cooling water consumed and withdrawn for EGUs in the western North American Continent on one-hour time intervals. The results of this analysis will yield insight into the potential merit of directing effort towards reducing thermoelectric water withdrawals in the southwestern US.

© ASCE 2014

Background

Water withdrawal data in the US are generally released every five years by the US Geological Survey (USGS); however, water consumption data (i.e., the subset of water withdrawals that is evaporated) has not been reported since 1995.[1,2] The US Energy Information Administration (EIA) reports cooling water consumption and withdrawal data annually for thermoelectric power generators through its EIA-860 form based on flow rate, but these data are often missing or erroneous, and lack temporal fidelity.

There are two types of cooling technologies that are used by the majority of EGUs in the US. Once-through (OT) cooling technologies withdraw large amounts of water from a river or water reservoir, use the water once to cool the hot steam exiting the turbine during power production, and then discharge the warm cooling water back to the original water reservoir. During this process, very little water is lost to evaporation since the water is only used once for cooling. Recirculating cooling systems, by contrast withdraw smaller volumes of water by recycling the water within cooling towers. Since water is cycled multiple times, most of the water that is withdrawn from the original water source is ultimately lost to evaporation, that is, it is consumed. Unlike OT cooling systems, RC cooling systems do not discharge large quantities of water back into the native water reservoirs.

Because of these differences in operational water requirements and varying impacts on the cooling source water reservoir, there are tradeoffs between these two technologies. OT cooling systems withdraw large volumes of water, but consume very little, which is therefore good for water availability compared to high water consumption technologies. RC systems require smaller volumes of water, but very little (if any) of the water that is extracted from a reservoir is ultimately returned to the water shed after generation. RC systems, therefore, can be less prone to generation disruptions in areas where water is constrained, but have larger evaporative losses than OT systems.

The distribution of OT and RC cooled EGUs varies regionally. Thermoelectric power generators in the western US use a larger fraction of RC cooling systems since the region is generally drier than the comparatively water-rich Eastern US. Eighty percent of the units of electricity generated in the eight most Western US (including Oregon, Washington, Idaho, Montana, Arizona, Nevada, New Mexico, and California) was produced in RC cooled facilities in 2005. (The majority of electricity generated in OT cooled facilities was produced along the coast and using saline cooling water.) By contrast, 54% and 46% of the electricity generated in the remainder of the Eastern US states is derived from OT and RC cooled facilities, respectively.[1] This trend reflects the fact that the Eastern US generally has more water available for withdrawal-intensive cooling facilities.

The Western Electricity Coordinating Council (WECC) is the regional entity within the North American Electric Reliability Corporation that coordinates and promotes reliable bulk power transmission across the western United States (i.e. Washington, Oregon, California, Idaho, Nevada, Utah, Arizona, Colorado, Wyoming, as well as portions of Montana, South Dakota, New Mexico, and Texas), Baja California, Mexico, and western Canada.[3] The WECC power grid provides a valuable case study for this research because it is the largest regional power coordination entity in North America, serving approximately 82 million people across 1.8 million square miles and includes the majority of North American regions that have experienced "extreme" or "exceptional" drought in the past decade.[3]

Table 1 details 2005 water use for thermoelectric electricity production in Eastern and Western US states. Freshwater withdrawals for thermoelectric power generation in eight Western

© ASCE 2014

US states (a large subset of the WECC territory) accounted for only about 4% of annual non-irrigation withdrawals in 2005 in those states. By contrast, in the remaining US states, water withdrawals for cooling thermoelectric power plants represented nearly 60% of total non-irrigation withdrawals. [1]

Methodology

The provision of electric power by WECC is governed by a unit commitment and dispatch (UC&D) system. This system meets demand by dispatching power generators in the order of least to greatest marginal cost, such that the most expensive generators might only operate a few hours per year.[4] Although this system is effective in minimizing wholesale generation costs, it does not consider other criteria in the dispatching of power regional such as water scarcity, which is large concern for many regions of the WECC territory.

Table 1. 2005 water use for thermoelectric electricity production in Eastern and Western US states [1]

	Oregon, Washington, Idaho, Montana, Arizona, Nevada, New Mexico, and California		All other US States	
Water Withdrawals for Thermoelectric Power Generation by OT and RC Cooling Systems	Million Gallons Per Day	Fraction of non-irrigation withdrawals in 2005Ŧ	Million Gallons Per Day	Fraction of non-irrigation withdrawals in 2005 Ŧ
OT (Freshwater)	730	2.1%*	130,000	50.9%*
OT(Saline)	13,000	94.0% **	45,000	94.6%**
OT (Total)	13,000	28.0%	170,000	58.0%
RC (Freshwater)	470	1.4%*	15,000	6.2%*
RC (Saline)	4.0	0.0%* *	470	1.0%**
RC (Total)	470	1.0%	16,000	5.4%
	Ŧ Fraction reflects proportion of *regional* water withdrawals			
	* Fraction of total regional freshwater withdrawals (excluding irrigation)			
	** Fraction of total regional saline withdrawals (excluding irrigation)			

© ASCE 2014

To perform this analysis, a publically available UC&D model[5] of the Western Interconnection grid was modified to consider water use rates across 3,600 electricity generation units (EGUs). The model, developed by WECC, simulates the projected grid operation for the year 2020 under an 18% Renewable Standard Portfolio with projected fuel costs in 2020. (The model runs using PLEXOS® Integrated Energy Model[6] software published by Energy Exemplar.)

Water consumption and water withdrawal rates were assigned to each generator accordingly its fuel type and cooling technology (i.e., OT or RC) based on water use rates defined by Macknick et al.[7] The water consumption and withdrawal factors applied in the UC&D model reflect the median values, in units of gallons per Megawatt-hour (MWh) of generation, reported in the study for respective generation technologies. The EIA's 860 and 923 forms were used to assign a cooling technology to each of the generators included in the WECC model and verify the operation of existing generators.[8,9] These data were cross-checked using county-level data from the USGS to verify the general ratio of RC to OT cooled generation (in units of generated electricity).

Next, the model was run to compute the generation, water consumption, and water withdrawals for 8760 hourly intervals for the year 2020. Since the model created a separate comma separated value (csv) file for each of the 3600 EGUs, a data post-processing program in MATLAB was created to aggregate hourly results (i.e. generation and water use) across a range of output metrics (i.e. fuel type, power plant cooling technology, and generation technology). The results were then plotted to analyze temporal patterns in generation, water consumption, and water withdrawals across the entire calendar year.

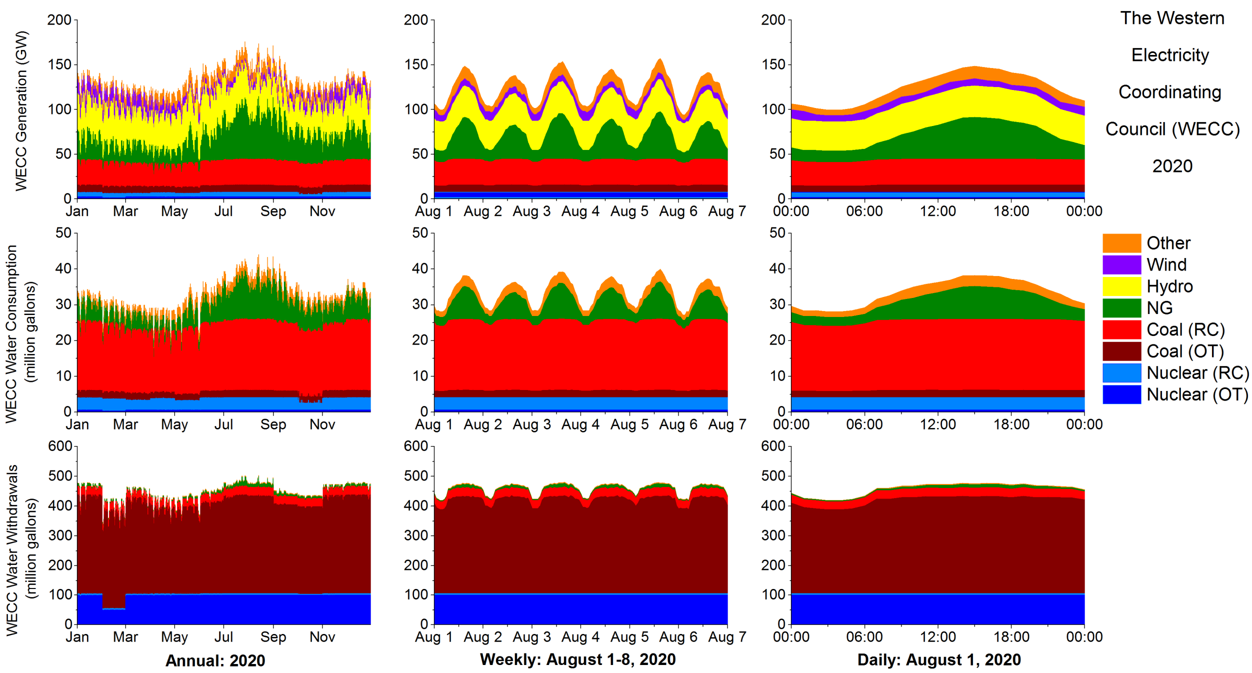


Figure 1. Projected electricity generation (top row), water consumption (middle row), and water withdrawals (bottom row) aggregated for approximately 3,600 EGUs in the Western Electricity Coordinating Council in 2020.

© ASCE 2014

Results

The temporal variation in selected output criteria for approximately 3,600 EGUs within WECC is summarized in Figure 1. The top, middle, and bottom rows represent 2020 electricity generation, water consumption, and water withdrawals across the entire WECC region, respectively. The first column summarizes annual trends across 8760 hourly timesteps, while the second and third rows illustrate a selected sample for a week and day in August, respectively.

Table 2. The results of the WECC model indicate that approximately 3,500 billion gallons of water will be consumed for power generation in 2020. (All values rounded two significant digits).

Technology	2020 Generation (GWh)	2020 Water Consumption (Billion Gallons)	2020 Water Withdrawals (Billion Gallons)
Nuclear (OT)	19,000	5.0	820
Nuclear (RC)	41,000	27	45
Coal (OT)	60,000	15	2,400
Coal (RC)	210,000	140	210
Coal (DC)	2,800	0.0056	0.028
NG Steam (RC)	24	0.0058	0.85
NG Steam (OT)	6,700	5.5	8.1
NGCC (OT)	0	0	0
NG CC (RC)	130,000	26	33
NG CC (DC)	3,300	0.0066	0.0066
NG (CT)	34,000	1.7	1.7
Hydro	320,000	0	0
Wind	94,000	0	0
Geothermal	35,000	9.5	9.5
Solar CSP	16,000	5.6	5.6
Solar PV	17,000	0.017	0.017
Biomass	15,000	4.5	4.5
Other	5,700	0	0
Total	1,000,000	240	3,500

OT = Once-through Cooled; RC = Recirculating Cooled; DC = Dry Cooling;
CSP = Concentrating Solar Power; PV = Solar Photovoltaic

Table 2 summarizes annual generation and water use estimates for power generation in 2020. Approximately 1,000,000 GWh of electricity are generated in 2020 (as compared to 885,000 GWh of historical generation in 2012[3]). This generation requires 3,500 billion gallons of water, of which, 240 billion gallons are ultimately consumed. This suggests that in 2020 electricity generation in WECC will require an average of 3.5 gallons of water per MWh generated. This average is much lower than the average US water intensity of thermoelectric power production in 2005, which approximately 22 gallons per MWh.[1] However, this trend makes sense for a few reasons. Firstly, the WECC generated only 20% of its power with once-

© ASCE 2014

through cooled EGUs (as compared to 50% nationally). Secondly, the WECC generated 45% of its total power generation with hydroelectricity, Solar Photovoltaic (PV) panels, wind, and dry-cooled (DC) systems that require trivial amounts of water for operation. (Nationally, these sources represented less than 10% of generation in 2012.[9])

Discussion

The temporal profiles illustrated in Figure 1 reflect the seasonal and daily variations in fluctuations in generation profiles. Seasonal fluctuations primarily reflect shifts in cooling and heating demands during warm and cool periods, respectively. Daily fluctuations occur due to the variation in energy demand across the day. For example, during the late nighttime and early morning hours, generation is lower since most people are asleep. Demand for electric power rises as people wake up and generally peaks in the late afternoon.

Figure 1 illustrates several trends regarding water use within the WECC. First, water use (both in terms of water consumption and water withdrawals) is distorted towards coal and nuclear power generators when compared against total generation. Coal-fired electricity generators cooled with RC systems had disproportionate water consumption per unit of electricity generated, while coal-fired electricity generators cooled with OT cooled systems had disproportionate water withdrawals. The same trend is observed for nuclear generators.

Some types of generation, such as wind and hydropower had no water use impacts. (It should be noted that the existence of a dam increases the net evaporation of a water reservoir in comparison to the natural run of the river, but this consumption is not included in this analysis since dams offer services other than power generation, such as recreation and flood control.) Solar PV (included in “Other” category) require nearly no water, other than for occasional cleaning. Solar Concentrating Power (CSP) and geothermal generation systems, also considered in the “Other” category, do have water impacts that can be as much or higher than fossil fueled generators.

One of the interesting outcomes of this study is the role of seawater cooling in the WECC. Seawater cooling at coastal power plants with OT cooling represented over 90% of the cooling water demand across Oregon, Washington, Idaho, Montana, Arizona, Nevada, New Mexico, and California in 2005.[1] (Most of this capacity currently exists in California.) However, recent policy changes in California suggest the phasing out of OT cooled systems in the state and possibly the nation. This rule would phase out a projected 6 GW of coastal power plant capacity, which is not accounted for in the 2020 scenario evaluated here.[10] It is not clear what the freshwater impacts will be of this resolution, but if this coastal capacity is replaced with thermoelectric EGUs that require freshwater it could add to existing water stress in California.

Conclusion

This study utilized a UC&D model of the WECC to project water consumption and water withdrawals in the year 2020. The results suggest that the average water intensity of generation in that year will be an order of magnitude less than the US average currently. Much of this reduction is due to the limited use of once-through cooled EGUs, as well as the expansion of water lean electricity generators. This model disaggregates water use into hourly time steps, which markedly increases the resolution of water use trends in the thermoelectric power sector for 3600 EGUs in WECC.

The results of this study will be used to create a spatial model of water use on a per EGU level with spatial and temporal fidelity. This model will be used to map the water requirements

© ASCE 2014

of each power plant in the context of local water availability, since some regions of the WECC are water-rich, while others are water-poor. Identifying the regions and power plants that are most drought prone and have high levels of water competition will be important for power and water planners alike to avoid lapses in power and/or water reliability.

References

(1) Kenny, J. F.; Barber, N. L.; Hutson, S. S.; Linsey, K. S.; Lovelace, J. K.; Maupin, M. A. "Estimated Use of Water in the United States in 2005," USGS, 2009.

(2) USGS "Estimated Use of Water in the United States in 1995," USGS, 1998.

(3) WECC "2012 State of the Interconnection Western Electricity Coordinating Council," Western Electricity Coordinating Council, 2013.

(4) Sanders, K. T.; Blackhurst, M. F.; King, C. W.; Webber, M. E.: The Impact of Water Use Fees on Dispatching and Water Requirements for Water-Cooled Power Plants in Texas. *Environmental Science & Technology* **2014**, *(in review)*.

(5) WECC: WECC PLEXOS Database 18 Percent Renewable Portfolio Standard. In *PLEXOS Datasets*; Western Electricity Coordinating Council, 2014; Vol. 2014.

(6) "PLEXOS® Integrated Energy Model " Energy Exemplar LLC, 2014.

(7) Macknick, J.; Newmark, R.; Heath, G. a.; Hallett, K. C.: Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature *Environmental Research Letters* **2012**, *7*.

(8) EIA "Form EIA-860 detailed data " U.S. Energy Information Administration, 2012.

(9) EIA "Power Plant Operations Report: Form EIA-923 " US Energy Information Administration, 2011.

(10) CA EPA. "Ocean Standards - CWA §316(b) Regulation," State Water Resources Control Board, 2014.

© ASCE 2014

Green Infrastructure to Reduce Stormwater Runoff in New York City: Post-Construction Monitoring over Multiple Years and Lessons Learned

John McLaughlin;[1] Matthew Jones, P.E., PhD;[2] William Leo, P.E.;[3] Thomas Newman, P.E.;[4] and Julie Stein, LEED AP, ENV SP;[5]

[1]New York City Department of Environmental Protection, 59-17 Junction Blvd, Flushing, NY 11373; (718) 595-4458; email: johnm@dep.nyc.gov
[2]Hazen & Sawyer, 4011 West Chase Blvd., Suite 500, Raleigh, NC 27607; PH (919) 890-4038; email: mjones@hazenandsawyer.com
[3]HDR, 1200 MacArthur Blvd, Mahwah, NJ 07430; PH (201) 529-5151; email: william.leo@hdrinc.com
[4]HDR, 1200 MacArthur Blvd, Mahwah, NJ 07430; PH (201) 529-5151; email: thomas.newman@hdrinc.com
[5]HDR, 500 7th Ave, New York, NY 10018; PH (212) 542-6073; email: julie.stein@hdrinc.com

ABSTRACT

Water quality in New York Harbor is currently impacted by combined sewage and stormwater discharges during large or intense rainfall events. In accordance with the 2012 Modified Combined Sewer Overflows (CSO) Consent Order, the New York City Department of Environmental Protection (DEP) will implement green infrastructure (GI) practices incrementally over the next two decades to manage one inch of runoff from 10% of its impervious surfaces in combined sewer areas citywide. In 2009, the City began designing, constructing and monitoring the performance of multiple pilot projects including enhanced tree pits, vegetated infiltration swales, rain gardens, blue roofs, pervious pavement, and underground infiltration systems to inform the citywide build-out of GI. These GI systems have been constructed in a variety of locations including in the right-of-way, highway medians, park-and-ride lots, public parks, and public housing facilities. Construction was completed in 2011 for most systems, with post-construction monitoring (PCM) of each completed system continuing over two years. Monitoring has been conducted to quantify inflow and outflow rates, ponding levels, drawdown rates, and water quality, and to examine maintenance needs and overall system functionality.

INTRODUCTION

In New York City, approximately half of the land area is served by combined sewers with the other half draining to separate storm sewers or directly to receiving waterbodies. Impervious surfaces cover approximately 70% of the city, and approximately 44 inches of rainfall in a "typical" annual year falls on these surfaces. In 2009, DEP initiated a pilot program to evaluate the performance of stormwater source controls in different areas of the City to determine effectiveness with varying land uses, subsurface conditions and localized climatic conditions. The GI systems were designed to comply with the runoff management target that served as the basis of the NYC GI Plan (and subsequently DEP's 2012 Modified Consent Order with the New York State Department of Environmental Conservation) and DEP's sewer connection rules updated to detain more stormwater on private and public development lots in combined sewer system areas. In addition, the monitoring program was used to track and document the required maintenance activities for two years following construction completion.

This paper describes several of the pilot facilities monitored and the associated quantitative hydraulic monitoring results for the two-year period. This paper presents results for selected storms and total capture of runoff for all monitored storms during the testing period to show how the performance of the GI systems vary with storm size and intensity, and other factors such as subsurface conditions, land use, upstream controls, and design.

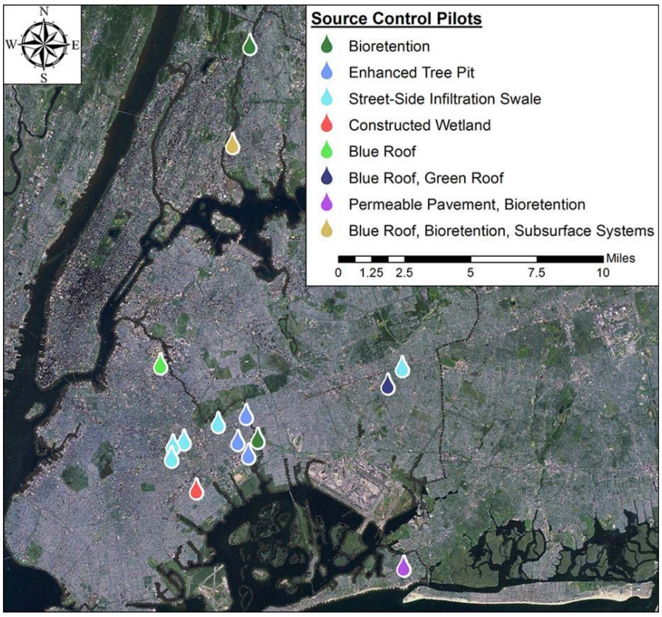
OVERVIEW OF PILOTS

Thirty GI pilot projects (the pilots) were designed and constructed to retain one inch of rainfall from contributing impervious areas or detain 0.25 cfs per acre before release to the combine sewer system. Combined, the pilots manage runoff from approximately eight acres of impervious area. The GI technologies designed and constructed included rooftop controls, porous pavement, subsurface storage/infiltration, and a variety of bioretention systems. All of the pilots were installed on city-owned property including the right-of-way (ROW), parking lots, public housing complexes, parks and schools. The spatial distribution of the pilot locations, depicted in Figure 1, was selected to test different subsurface conditions (i.e., soil types and depth to bedrock).

FINDINGS

"Blue roofs" are rooftop detention systems designed to slow down the runoff during rainfall events. The goal is to reduce or "shave" peak flow rates, thereby reducing or eliminating CSO events. Blue roofs consist of controlled flow roof drains and check dams or trays with orifices to slowly discharge roof runoff to the sewer system. Compared to green roofs, blue roofs lack vegetation and related functions such as uptake from water stored in the soil media and evapotranspiration. However, blue roofs should offer reduced capital and maintenance costs compared to green roofs. Blue roofs were piloted to confirm their performance and installation and maintenance advantages compared to green roofs.

Figure 1: Locations of GI Pilots in New York City

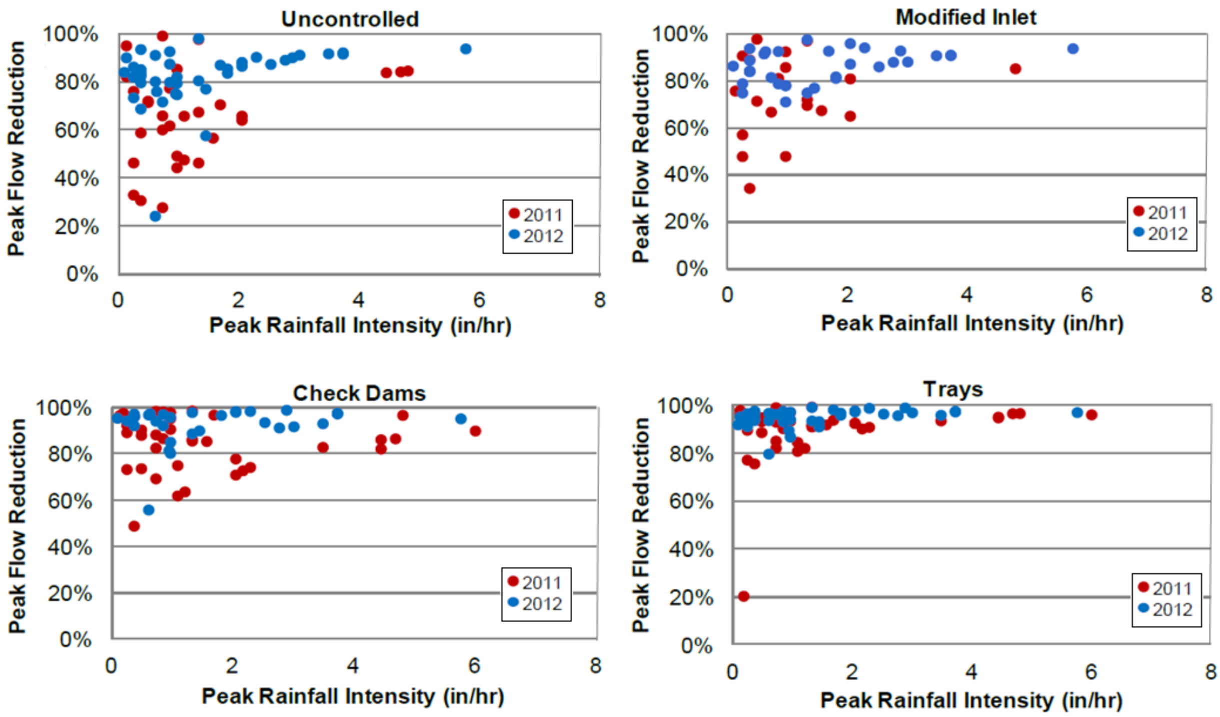


One of the blue roof pilots is testing multiple designs on a single rooftop of a DEP storehouse building located in northern Brooklyn. The 27,500-square foot rooftop is divided into four quadrants: (1) an unmodified roof area, to serve as a control for testing; (2) a roof area retrofit with a modified inlet control featuring a 2-inch collar to raise ponding depth and a 1-inch orifice to slow inflow; (3) a roof area retrofit with a series of concentric, 2-inch high check dams made of inverted aluminum 'T's with ¼-inch holes drilled to detain runoff; and (4) a roof area featuring ballast-filled trays (adopted from green roof trays) and geotextile fabric to slow the flow through ¼-inch holes drilled into the bottom of each tray.

As Figure 2 illustrates, the controls applied to the different quadrants provide varying levels of peak-flow reduction. The results shown include approximately 70 storms in 2011 and 2012 for which reliable monitoring data were collected and analyzed. All the controls provide good peak shaving, with the trays providing consistent reductions of about 80-100% across all storms. However, the unmodified or uncontrolled roof quadrant also is shown to reduce peak flows by 20-90% due to existing "depression storage" and other factors such as antecedent precipitation (i.e., how much rain has already fallen). Additional analysis of the monitoring data shows that blue roofs provide good volume reduction/retention results with the trays performing best (i.e., 50-80% retention volume capture) despite the fact that the Blue Roofs were designed for detention or peak shaving only .

© ASCE 2014

Figure 2: Blue Roof – Performance for Peak Flow Reduction

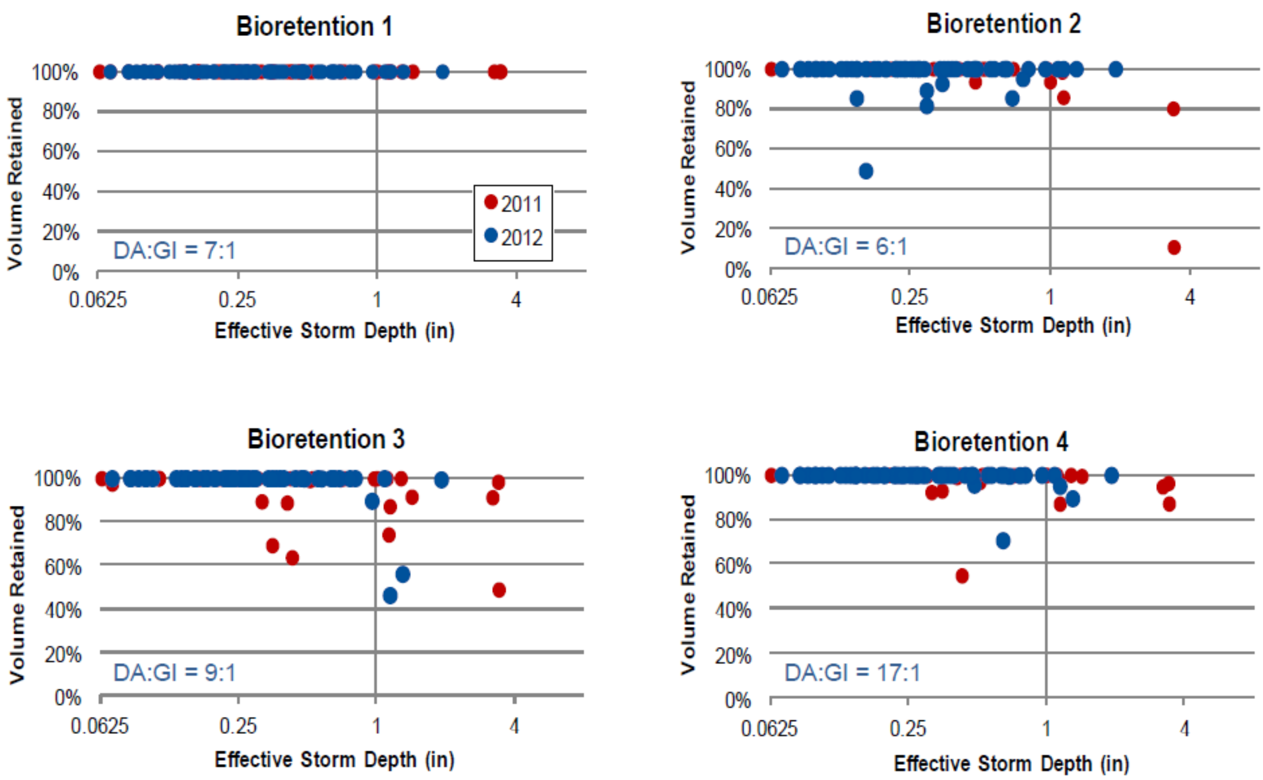


Monitoring data was also collected for several bioretention installations including multiple cells surrounding a community center at a public housing complex in the Bronx. The bioretention cells or “rain gardens” were all designed to retain one inch of runoff from tributary areas of different sizes; the ratios of drainage area to GI practice “footprint” area ranged from 6:1 to 17:1. Runoff from adjacent impervious surfaces is routed into the bioretention cells via curb cuts. A surface depression within the cell allows water to pond and permeate through the engineered soil and gravel layers before infiltrating into the underlying soils. While the soils are suitable for infiltration in this area, high bedrock elevations are prevalent throughout the site and the cells were constructed with underdrains to prevent prolonged or nuisance surface ponding.

As shown in Figure 3, the four bioretention cells constructed around the community center function very well in terms of volume retention across approximately 70 storms monitored. Bioretention cell number 1 fully retained 100% of the runoff that entered the cell for every monitored storm in 2011 and 2012. The other cells show several rainfall events with less than 100% retention. Site-specific factors such as soil types and infiltration rates limited the retention capacity of these cells, particularly for storms with higher rainfall intensity and/or shorter periods of antecedent dry weather.

Evaluation of the ponding depth in particular cells during individual storm events reveals that each of the cells drained down within 8 hours following rainfall. For a single, 1- to 1.5-inch storm, each cell fully drained down within 3-4 hours, again dependent on the factors cited above.

Figure 3: Rain Gardens – Performance for Volume Retained
(DA:GI denotes drainage area size to GI feature size ratio)



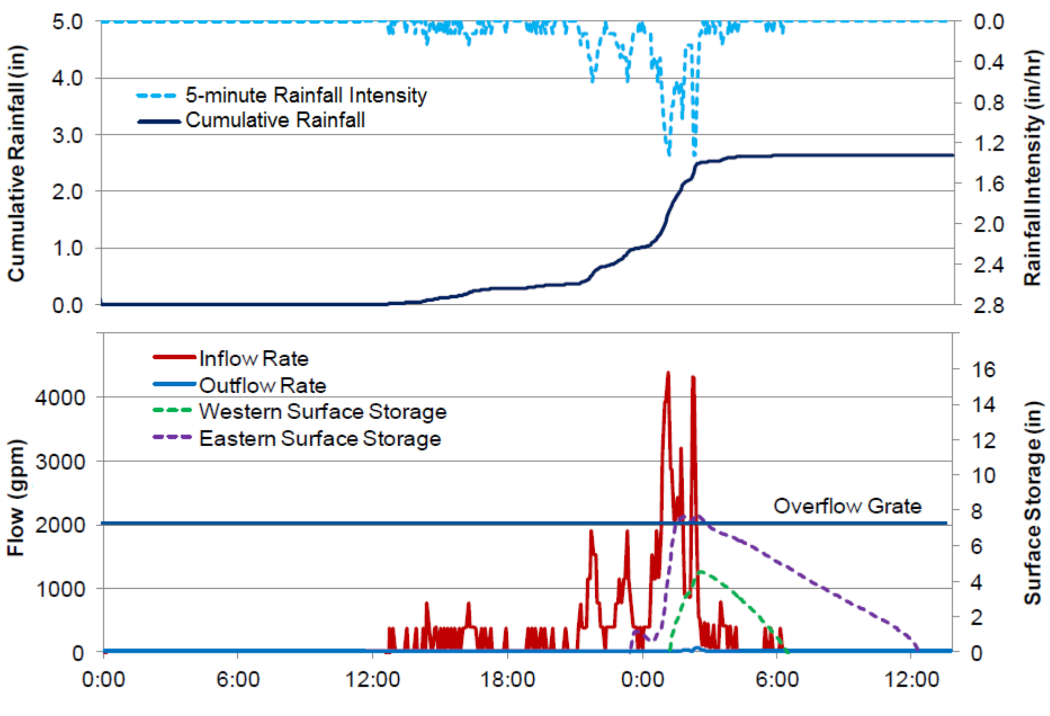
Draindown time as influenced by rainfall volume and intensity was also analyzed at another bioretention pilot installation. A series of two interconnected bioretention cells was designed and constructed within a parkway median in southern Queens. The cells combined cover 7,400 square feet of surface area to manage approximately 81,870 square feet of impervious surfaces. For this facility, the drainage area to GI feature area ratio is 11:1. The size of the median plus the topography of the area allows much of the flow to be conveyed from surrounding streets and sidewalks via curb cuts and vegetated swales, and the underlying sandy soils are optimal for infiltration. Therefore, the exceptional performance of this parkway median bioretention system in terms of volume retention resulted from these

© ASCE 2014

ideal conditions. Over the course of 2011-2012, only four out of the approximately 70 storms resulted in overflow, despite storms ranging from 0.1 to 7.8 inches and intensities of up to 4.9 inches per hour.

Figure 4 below represents data analyzed for a single storm to illustrate how the system functions during and following a storm event. The upper panel presents the rainfall intensity (light blue line) and cumulative rain (dark blue line) over the course of the storm measured at the site. The lower panel presents the runoff from the drainage area entering the facility (red line), the ponding depth within each of two cells (dashed purple and green lines), and the overflow from the facility (light blue line). As shown, ponding depth in the cells only briefly reached the overflow threshold and overflow from the facility was minimal during this 2.64-inch storm event. After the rain ended, the ponded water drained down completely within eight hours. Over the 2-year monitoring period, vegetation became more established and maximum drawdown rates improved. Time needed to drain down from maximum ponding depth dropped from 24 hours to 15 hours. These drain-down times are much less than the 48 or 72 hours typically referenced as the duration of ponding that may affect public health and safety, particularly in densely developed areas like the location of this GI pilot.

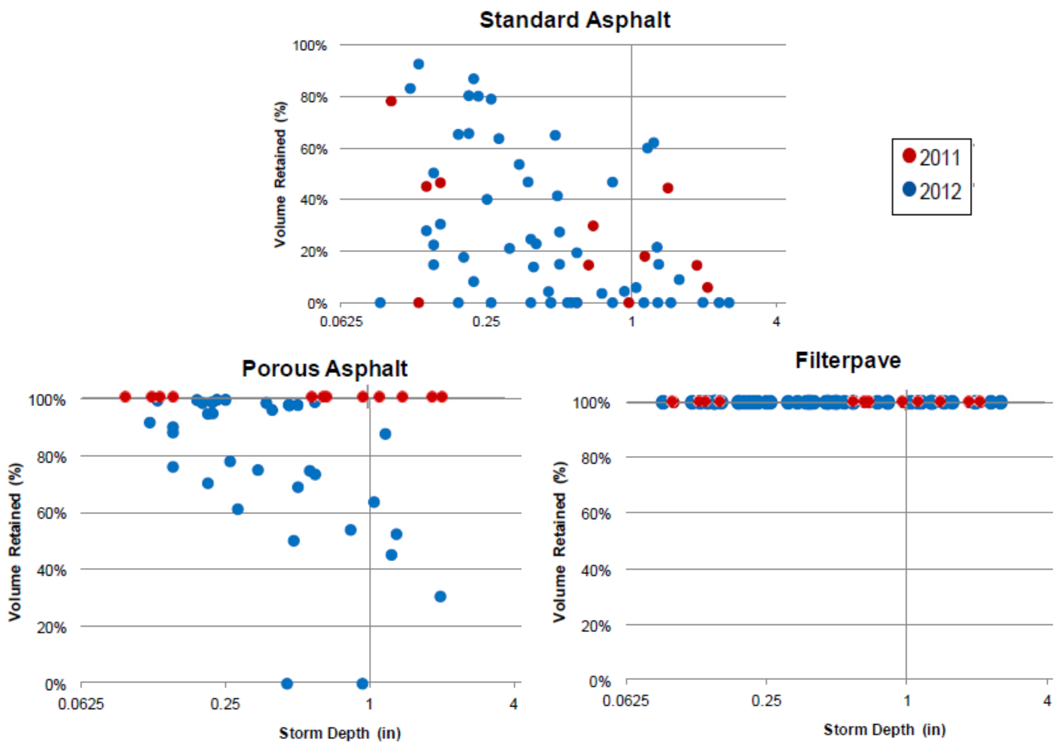
Figure 4: Roadway Median – Performance during 2.6” Storm (June 12, 2012)



Permeable pavement was also tested as part of DEP's pilot monitoring program. One such pilot featured three repaved areas in a City-owned bus terminal parking lot. The center area was repaved with standard asphalt and the areas on either side were repaved using two different types of permeable pavement: porous asphalt, and a proprietry product (FilterPave™) made from crushed glass. All paved areas were pitched so that they drained to three separate collection points where flow was monitored. The subsurface of the porous asphalt and proprietary product were designed with 18 inches of gravel-filled storage and an underdrain pipe. The native soils below are predominately sand with permeability rates of 6 to 7 inches per hour.

The results in Figure 5 show that the FilterPave™ consistently captures and retains 100% of all rainfall whereas the porous asphalt and standard asphalt results varied, with porous asphalt capturing greater than 50% of rainfall. However, concurrent observations during the monitoring program highlighted that FilterPave™ is wearing down (i.e., chipping/rutting) and may not score as highly in terms of durability compared to the other two surfaces, which show no signs of wear. In 2012, FilterPave was coated with an epoxy to enhance its durability. This represents the only maintenance activities performed for all surfaces at this pilot location.

Figure 5: Permeable Pavement – Performance for Volume Retained



© ASCE 2014

In addition, the pilot monitoring program includes several "enhanced tree pits" to test GI in the right-of-way and areas of different soil types and determine the optimal drainage area to GI practice ratio. These enhanced tree pits were monitored for volume retention benefits and also observed throughout the monitoring period to enhance design, minimize runoff bypass and streamline maintenance activities. As a result, these "first generation" designs evolved into improved standard designs for right-of-way bioswales which DEP is currently relying on to achieve its interim milestones for citywide GI build-out.

With assistance from the project team, DEP was also able to evolve its monitoring program. Currently, data are being collected from flow meters installed within isolated segments of the combined sewer draining three separate areas where multiple GI practice have been installed. In 2013, additional equipment such as temperature sensors and low-lying cameras was installed at several GI installations to measure "co-benefits." DEP is also currently applying similar monitoring methods and protocols to collect and analyze specific to the water quality treatment benefits provided by GI to be constructed in separate storm sewer areas for New York City's draft MS4 permit.

CONCLUSIONS

DEP's GI pilot monitoring program focused on data collection and analyses that would document the effectiveness or ineffectiveness of GI designs and construction toward managing 1-inch of runoff and updated stormwater regulations requiring greater detention onsite. Over the course of the two-year monitoring period, consistent, quality-controlled results with respect to these metrics were produced and reported. As a result, DEP has gained confidence that GI can be designed and constructed to achieve citywide goals with respect to managing runoff closer to its source and reducing runoff that enters the combined sewer system.

The results presented herein provide a subset of the types of GI piloted and the results produced. The 2-year pilot monitoring program served to quantify the hydraulic performance of actual GI installations and revealed many of the relevant factors and limitations that should be considered for widespread implementation. The pilot monitoring program helped to produce design improvements and long-term maintenance needs, and provided a foundation informed by lessons learned for subsequent monitoring of programs. Today, DEP is actively monitoring sewer system impacts from larger, neighborhood-scale installations as well as co-benefits associated with GI. As such, these pilots have served as the basis of understanding and designs for DEP's current citywide GI implementation program to manage 1 inch of runoff from 8,000 acres citywide as required by the 2012 Modified CSO Consent Order and DEP's ongoing GI research and development (R&D) efforts.

© ASCE 2014

ACKNOWLEDGEMENTS

We would like to acknowledge the research and development initiatives at DEP for funding this pilot program and applying the results of the study to assist mandated programs as well as enhance the overall sustainability of New York City. Special thanks to John McLaughlin for his emphasis on science-based investigations and leadership prior to and during the pilot study. This was very much a team effort that could not have been completed without the expertise from HDR, Hazen and Sawyer, Biohabitats, Horsley Witten Group, Geosyntec, and Brooklyn College. Annual monitoring reports can be found on DEP's website: www.nyc.gov/dep.

© ASCE 2014

Water Budget Triangle: A New Conceptual Framework for Comparison of Green and Gray Infrastructure

C. G. Eger,[1,2] D. G. Chandler,[2] B. Kasaee Roodsari,[2] C. I. Davidson,[2] and C. T. Driscoll[2]

[1] Syracuse University Center for Sustainable Community Solutions, 727 East Washington Street, Syracuse, NY, 13244; PH 315-443-3641; email: cgeger@syr.edu
[2] Department of Civil and Environmental Engineering, Syracuse University, 151 Link Hall, Syracuse, NY, 13244 email: chandler@syr.edu

ABSTRACT

A new ternary plot tool, the Water Budget Triangle, is described and examined for comparing hydrologic functions of unlike systems. The tool is intended as a visual indicator of the distribution of mass outflow among event runoff (Q), evapotranspiration (ET), and percolated or stored drainage (I) to evaluate and compare GI technologies. The same tool may be used to plot other stormwater systems such as storm sewers, cisterns, and detention or retention ponds for comparison and reference. This tool may be used as an analytical monitoring device to identify "normal" operating zones for individual installations of classes of systems, and also as a diagnostic tool to identify systems that are not functioning within their intended range.

INTRODUCTION

Recent research in green infrastructure (GI) design has produced a wide variety of low impact development (LID) structures, constructed ecosystems, and catchment devices with the aims of diverting stormwater runoff from combined sewer systems, alleviating flooding or adhering to total maximum daily pollutant load limits. As monitoring projects emerge and begin to gather valuable data on GI performance, there is a critical need to compare and contrast studies and information. Unfortunately, common metrics do not exist for comparing and evaluating the hydrologic function of these systems. Each type of GI has a different hydrologic behavioral function, and each individual installation likely exhibits its own range of performance in different climatic zones and different urban landscape settings. The range of variability in hydrologic function and performance may give the appearance that bioretention, green roofs and other GI technologies are less reliable than traditional gray infrastructure, which operates at a comparatively predictable discharge rate. As a result, the engineering community has expressed concerns about the risks of adopting best management practices that have a wide range of possible responses, and do not exhibit a standard operational range. Concerns about lack of predictability may also relate to the absence of simple metrics to compare and contrast green and gray systems in a straightforward, meaningful way. A new tool

© ASCE 2014

that permits such comparisons could provide water system managers and engineers a common decision metric supported by on-site performance data to guide cost-effective and appropriate application of GI. This tool compiles and presents complex technical information in a simple, visual format that may be easily interpreted by technical and non-technical users and should be useful to interpret and communicate how different engineered systems capture and process storm runoff over both short or long timescales.

DESCRIPTION OF THE TOOL

A ternary graph, or triangle plot, depicts the ratios of three variables that sum to 100%. The soil texture triangle developed by USDA is a well-known example of a triangle plot, which aggregates three axes of information (sand, silt and clay) to classify soils according to physical properties (NRCS 2014). Most civil, environmental and agricultural engineers are familiar with soil texture triangles in the context of specifying fill characteristics for engineering design, although many ecologists, agronomists and soil scientists also use this tool to classify naturally occurring environmental conditions. We propose a new, equally versatile triangle plot tool to visualize the distribution among three hydrologic fluxes important to engineered water systems, including both “green” and “gray” stormwater infrastructure (Figure 1). The tool assumes that after influent stormwater enters a system there are three pathways controlling its fate:

1. Water may be discharged from the system as flowing runoff (Q, right axis);
2. Water may evaporate or transpire into the atmosphere (ET, top axis); or
3. Water may drain via percolation into the soil/groundwater system (I, left axis).

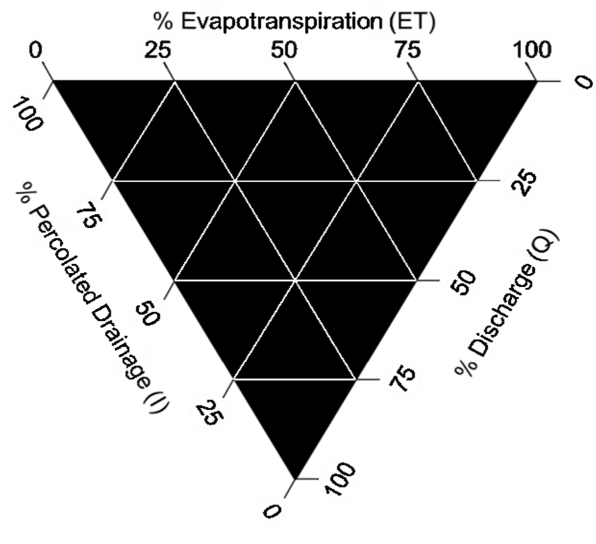


Figure 1. Water Budget Triangle

This tool uses a water balance approach to account for phase changes and divergent hydrologic processes. The sum of the three plotted values is equal to 100%, representing the total mass of water exiting the system. The vertical distance of any point from the lower vertex of the ternary plot represents the discharge reduction efficiency of the system (Figure 2): systems operating at the lower vertex exhibit no runoff reduction, while systems operating anywhere along the top axis capture all run-on during the monitored time-step, achieving a “zero discharge” event.

© ASCE 2014

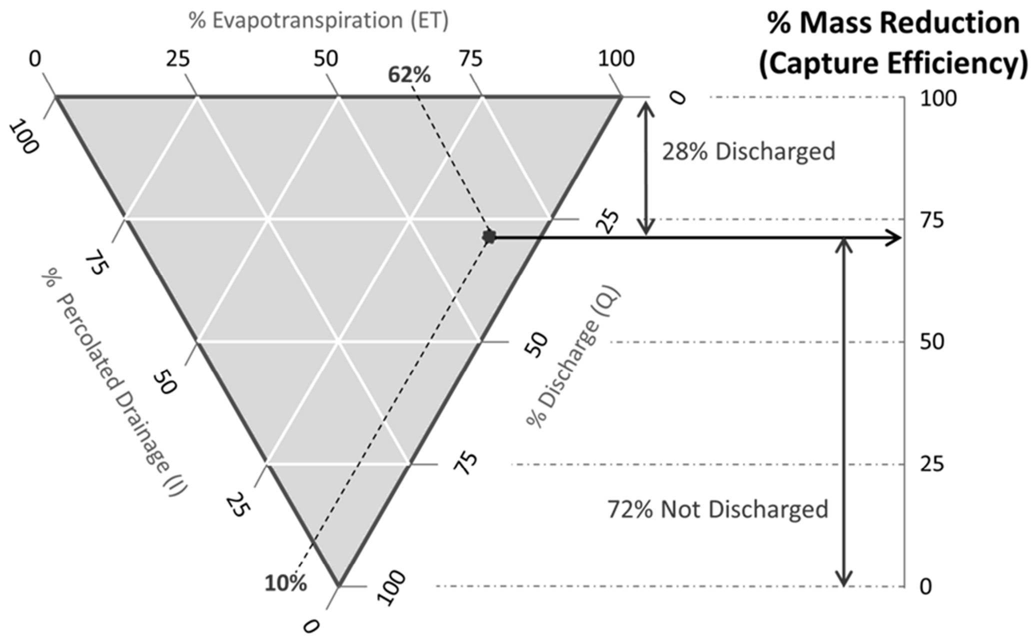


Figure 2. Vertical distance from the lower vertex of the Water Budget Triangle tool visually represents system capture efficiency. The plotted point depicts the distribution of hydrologic loss at Q = 28, ET = 62, I = 10.

COMPARISON OF GREEN AND GRAY INFRASTURCTURE SYSTEMS

We anticipate that different types of stormwater management, which manifest contrasting hydrologic function, can be readily depicted on the Water Budget Triangle, and theorize about the placement of several system types. Examples of hypothetical system ranges with plots of previously published data from existing systems are shown in Figure 3.

Gray infrastructure, sewers and conveyance systems. Conventional infrastructure, including storm sewers, combined sewer overflows and regional collectors are designed primarily for conveyance and to discharge at a point. However, most existing storm sewer systems are not watertight, because they usually do not have gasketed joints and may shift due to fine losses and ground heaving (ASTM 2011, 2013, 2014). This condition can result in substantial seepage to surrounding soil (I >> 0), possibly tens of thousands of gallons per day or more (Kurdziel 2002; Bhaskar and Welty 2012). In comparison with total mass of water conveyed and discharged by most sewer systems (upward of millions of gallons per day), the total seepage is unpredictable; it could be very low due to high groundwater pressure (Q >> I), or as much as 40% of the total water exiting the sewershed (Q ≈ I) (Bhaskar and Welty 2012). Evapotranspiration is negligible in subterranean conveyance systems (ET ≈ 0), thus combined sewer systems plot along the lower left axis of the triangle tool; the ideal conveyance system (zero seepage loss to ground) plots at the lower vertex (Q = 100).

© ASCE 2014

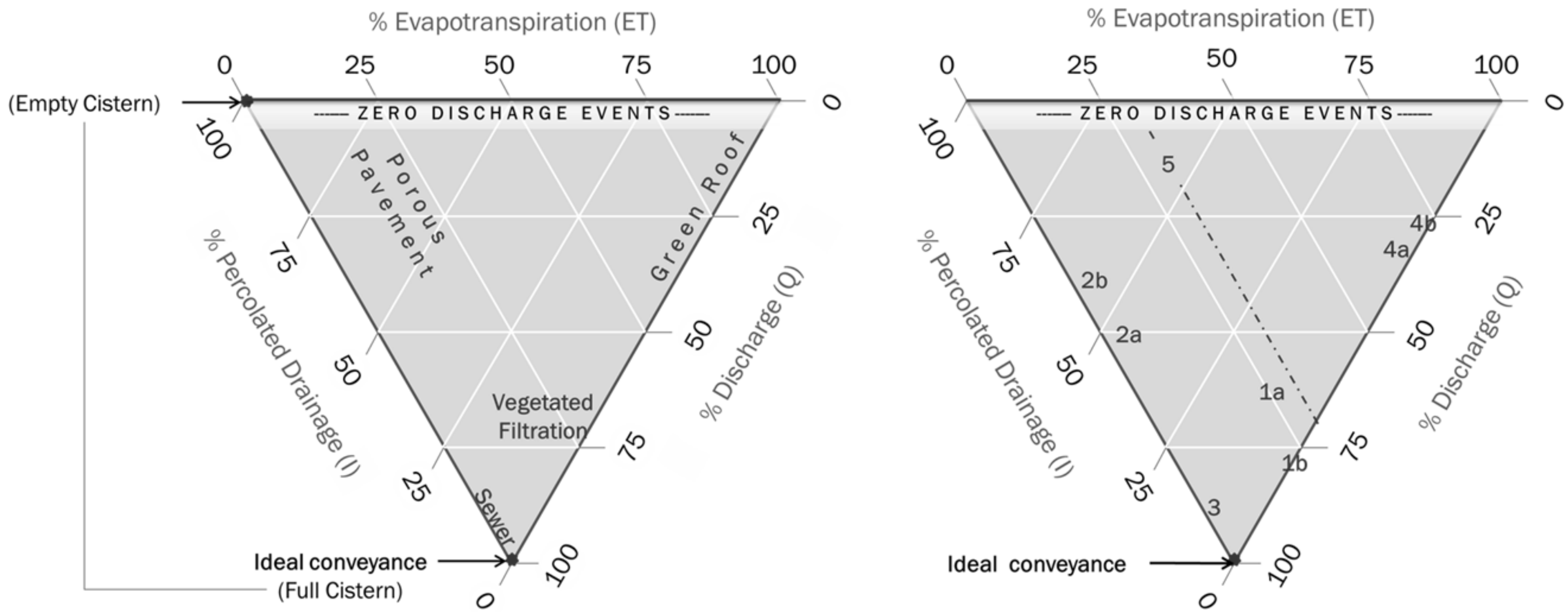


Figure 3. Hypothesized placement of stormwater systems on the Water Budget Triangle (left) and data from published literature (right), represented by letters and numbers: Li et al. (2009) report annual water balance for two bioretention cells, unlined (1a – 65% filtered Q, 25% ET, 10% exfiltration to surrounding soil) and lined (1b – 79% filtered Q, 21%ET, 0% exfiltration) in Louisberg, NC. Brown and Hunt (2011) report water budgets for two undersized bioretention cells in Nashville, TN (2a – 50% filtered Q, 5% ET, 45% exfiltration) and (2b – 35% filtered Q, 5% ET, 60% exfiltration). Zhang and Mitsch (2005) report average daily water budget for two constructed wetlands at the Olentangy River Wetland Research Park in Columbus, OH (3 – 84% Q, 2% ET, 14% I) for four years of data. Wadzuk et al. (2013) report annual water budgets for a green roof in Philadelphia, PA for 2009 (4a – 29% Q, 68% ET, estimated 3% I) and 2011 (4b – 26% Q, 73% ET, estimated 1% I). Nemirovsky et al. (2013) estimated an evapotranspiration limit at 30% of total mass flux for porous pavement (5).

© ASCE 2014

Bioretention, swales, and infiltrative systems. Bioretention cells and rain gardens are not expected to perform at the same plot point for each inundation event, due to differences in discharge proportion among events of differing magnitude and intensity. Cells and swales that have very high catchment sizing ratio, deeper storage capacity, or are sited on permeable substrates well above the local groundwater surface plot near the left side of the triangle, where percolation dominates (I > ET and Q).

Vegetated filtration. Vegetated filter strips, or buffer strips, offer little percolation or storage capacity (I < Q); however, they allow for rapid filtration of water with the aim of reducing effluent pollutant loads such as total suspended solids and particulate organic and nutrient matter (Stagge et al. 2012). Vegetated filter strips should plot close to the lower right axis, point 1b on Figure 3 represents a true vegetated filter from Li et al. (2009).

Stormwater retention and detention ponds. Detention ponds (dry ponds) and retention ponds (wet ponds) are common stormwater technologies in the US (Fischer et al. 2003). Retention ponds are engineered with a compacted substrate (to limit percolation and maintain standing water), and low surface area to volume ratio (to maintain sparse emergent vegetation, which limits ET). When plotted on the Water Budget Triangle, retention ponds may prove to perform similarly to a "filled cistern." Detention ponds are engineered to store water for short periods of about 6-48 hours to reduce peak flows; there is little information about comprehensive water budgets partitioning ET or groundwater recharge (I) in these systems (WEF 1998). Individuals using the triangle tool to study detention ponds must determine the appropriate time scale to partition stored drainage (I) and "event runoff" (Q). Impounded water stored in a detention pond or cistern during the event hydrograph may be considered as beneficial to the watershed only if released very gradually to the stream during baseflow, and is effectively the same as percolated drainage.

Wetlands. Constructed and natural wetlands exhibit a wide range of hydrologic behaviors; for example, kettle wetlands have zero discharge and water loss can oscillate seasonally between evapotranspiration and infiltration dominance, depending on temperature and precipitation (Hollands 1990). The triangle tool is useful to visualize such hysteretic behavior across daily, annual or longer time scales, and may also indicate design options to help constructed wetlands more closely mimic beneficial aspects of natural wetland function.

Green roofs. Both extensive and intensive green roofs often operate as zero-discharge systems (Q = 0) below a minimum event threshold (flux lost to soil profile is very limited, therefore I ≈ 0). Roof media storage volume limits ET and is highly dependent upon the depth of the media and the porosity, and to a lesser extent on the carbon content (Wadzuk et al. 2013; Jarrett and Berghage 2014). In turn, ET loss depends on storage volume, the ambient temperature and some function of roof vegetation. Under low precipitation events, functioning green roof systems are

© ASCE 2014

expected to plot close to or on the upper right axis of the triangle tool, with larger events plotting progressively closer to the lower vertex (Q increases with event size).

Porous and permeable pavement. Porous pavement is intended to promote infiltration (I), but if it is not adequately maintained, precipitation will run off the surface (Q). Although infiltrative capture of porous pavement has been studied since 1989, evaporation has not been well studied. As a result, there is a perception that evaporation is minimal for permeable pavement systems; Hunt and Collins (2008), assume fluxes from subsurface storage are primarily to discharge and percolation. Black pavement heats substantially when exposed to sunlight, so it may be erroneous to plot permeable pavement systems along the left side of the triangle tool ($ET \neq 0$). Nemirovsky et al. (2013) discuss the evaporation behaviors of different types of pervious pavement systems. They describe the range of evaporation influence between zero and 30% (possibly more), depending on the sizing and porosity of the system and the number of days between precipitation or run-on loading.

Rainwater harvesting systems. Cisterns and other impervious rainwater harvesting devices constructed specifically for storage plot along the left axis of the Water Budget Triangle. The vertical position depends on the ratio of storage to event depth and whether the harvested water is withdrawn between events. A cistern with excess capacity would plot at the top left corner of the triangle (I = 100), whereas a full cistern would plot at the lower vertex (Q = 100). Individual rain barrels, (usually <55 gal or 210 L), seldom capture a substantial portion of runoff from a residential roof (EPA 2014), less if barrels are not emptied between storm events. The triangle can be used to examine the impact of introducing many small barrels to a watershed in mitigating storm runoff. Using barrels without weep holes or other automatic post-event discharge may not be an effective stormwater management strategy. Future work using the triangle could help to identify a size range for effective water harvesting that targets a specific runoff reduction goal.

LIMITATIONS OF THE TOOL

As with every model, this tool has limitations. Primarily, it displays proportional information, not actual mass measurements of discharge, evapotranspiration or percolation. Two systems plotted at the same point on the triangle may operate in the same manner, but may represent total outgoing masses that are considerably different in magnitude. The user should not confuse the ratio of mass lost from the system (as a percentage) with the actual volumetric or mass measurement (cubic meters or kg) of water. One useful aspect, however, is the ability to compare the performance of small-scale systems with larger scale ones, and thus a researcher can use the triangle to plot the performance of laboratory columns or pilot systems on the same figure as both field cells and traditional drainage systems. This approach will help LID designers and engineers to understand how systems change as scale and size increase.

The triangle tool also does not take into account influent characteristics, the source of water entering the system, or the pollutant load entering the system. It is limited to

© ASCE 2014

comparing only the ratios of the three pathways of water exiting from the system. This requires the user to be accurate and precise about defining the spatial and temporal bounds of the system in study, because there is potential for confusion over sources and sinks of water that do not fit into the three categories or when time affects the function of the system. For example, water that enters a system and initially infiltrates into ground storage may evaporate or transpire over the course of several hours or days, so the data should be collected and plotted in a method that reflects understanding of these dynamics. The user should also not assume that influent mass from run-on or precipitation is automatically equivalent to outgoing total mass, because this assumption does not account for the existence of stored water within the system before it is loaded. If a system loses stored water in addition to influent water, the total outgoing mass may exceed the actual incoming mass.

Lastly, it is difficult for hydrologists to gain closure on a water balance (e.g., in Wadzuk et al. (2013), ET plus discharge exceeds precipitation in 2010). Obviously, there is some amount of measurement error in each term that is measured directly. However, ET to atmosphere and percolation to groundwater can be quite difficult to separate, because the fluxes are small, difficult to measure and occur over long time scales. One or both of the measured terms often include the error from all other terms, which may present a dilemma about where to attribute the residual error. Future examination of the Water Budget Triangle could present some discussion of how uncertainty and variability affect ability to readily identify "normal" operational ranges for various systems. As mentioned, system performance is not expected to remain static through time; this may be due to a range of performance under different initial conditions or factors specific to the individual storm event, including initial storage, frequency and intensity of precipitation (affecting I and Q), seasonality (affecting ET), use of harvested water in a cistern (affecting Q), and other conditions. This tool may prove most useful to demonstrate the expected range of performance of an individual technology depending on initial conditions or season and further the development of more careful design, maintenance and operations practices.

SUMMARY

Although untested, the Water Budget Triangle offers potential advantages for scientists and engineers studying green infrastructure performance. It allows visual reference of capture efficiency, and a comparative range for living and non-living low-impact devices, as well as traditional gray infrastructure systems. The Water Budget Triangle is now a readily adoptable tool for scientists and engineers to study and evaluate new and existing civil infrastructure practices.

REFERENCES

ASTM Standard C1628 – 11. (2011). "Standard specification for joints for concrete gravity flow sewer pipe, using rubber gaskets." *ASTM International*. West Conshohocken, PA. <www.astm.org> (June 15, 2014).

© ASCE 2014

ASTM Standard C1478 – 08. (2013). "Specification for storm drain resilient connectors between reinforced concrete storm sewer structures, pipes and laterals." *ASTM International*. West Conshohocken, PA. <www.astm.org> (June 15, 2014).

ASTM Standard C14 – 14. (2014). "Specification for nonreinforced concrete sewer, storm drain, and culvert pipe." *ASTM International*. West Conshohocken, PA. <www.astm.org> (June 15, 2014).

Bhaskar, A. S. and Welty, C. (2012). "Water balances along an urban-to-rural gradient of metropolitan Baltimore, 2001-2009." *Env. & Eng. Geoscience*, 18(1), 37-50.

Brown, R. A. and Hunt W. F. (2011). "Impacts of media depth on effluent of water quality and hydrologic performance of undersized bioretention cells." *J. Irrig. Drain Eng*. 137, Special Issue: Urban storm-water management in the 21st century, 132-143.

Fischer, D., Charles, E. and Baehr, A. (2003). "Effects of stormwater infiltration on quality of groundwater beneath retention and detention basins." *J. Environ. Eng*. 129(5), 464-471.

Hollands, G. G. (1990). "Regional analysis of the creation and restoration of kettle and pothole wetlands." In *Wetland Creation and Restoration: The Status of the Science*. Kusler, J. and Kentula, M. eds. Island Press, p. 281.

Jarrett, A. R. and Berghage, R. D. (2014). "Green roofs." *Penn State Extension*. Online Factsheet. <http://extension.psu.edu/natural-resources/water/discovery-watersheds/stormwater/green-roofs> (July 10, 2014).

Kurdziel, J. (2002). "The evolution of watertight storm drainage systems." *Pipelines 2002: Beneath our feet: Challenges and Solutions*, *ASCE*. Cleveland, OH: 1–9.

Li, H., Sharkey, L. J., Hunt, W. F. and Davis, A. P. (2009). "Mitigation of impervious surface hydrology using bioretention in North Carolina and Maryland." *J. Hydrologic Eng*. 14(4), 407-415.

Nemirovsky, E. M., Welker, A. L. and Lee, R. (2013). "Quantifying evaporation from pervious concrete systems: Methodology and hydrologic perspective." *J. Irrig. Drain Eng*. 139(4), 271-277.

Natural Resource Conservation Service. (2014). "Soil Texture Calculator." *USDA*. <http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/tools/?cid=nrcs142p2_054167> (June 18, 2014).

Stagge, J., Davis, A. P., Jamil, E. and Kim, H. (2012). "Performance of grass swales for improving water quality from highway runoff." *Water Res*. 46(20), 6731-6742.

U.S. EPA (2013). "Rain barrels." *Mid-Atlantic Region Green Landscaping*. <http://www.epa.gov/reg3esd1/garden/rainbarrel.html> (July 7, 2014).

Wadzuk, B., Schneider, D., Feller M., and Traver, R. (2013). "Evapotranspiration from a green-roof storm-water control measure." *J. Irrig. Drain Eng*. 139(12), 995-1003.

WEF Manual of Practice No. 23 (1998). *Urban Runoff Quality Management*. ASCE.

Zhang, L. and Mitsch, W. J. (2005). "Modelling hydrological processes in created freshwater wetlands: An integrated system approach." *J. Env. Soft*. 20, 935-946.

© ASCE 2014

Defining and Measuring Sustainable Transport Solutions

Fares BEAINY; Sebastian WIKANDER; Aleksander PODOLAK; Lei LI; Toshiaki CARRHAGIWARA

[1] Research Engineer, Emerging Technologies, Advanced Engineering, Volvo Construction Equipment, Shippensburg, United States
[2] Project Manager Supply Chain, Material & Order, Volvo Group Trucks Operations, Ageo, Japan
[3] Supply Chain Management Specialist, Supply Chain Management, Volvo Buses, Wroclaw, Poland
[4] Materials Management Business Analyst, Materials Management APAC, Volvo Group Trucks Operations, Singapore, Singapore
[5] PD Engineer Pneumatic Structure, BSVC-Brake System & Vehicle Control, Volvo Group Trucks Technology, Ageo, Japan

ABSTRACT

A sustainable infrastructure improves the short and long-term economic and environmental performance while taking the impact on society into consideration. In order to create a sustainable infrastructure there are a number of underlying components such as transport, energy, water, communication, solid waste, etc. that needs to be addressed. For each component in turn, sustainability is influenced by different factors such as planning, design, construction, operation, and maintenance. In addition, the impact of different entities such as governments, international organizations, local authorities, construction companies, and materials and tools manufacturers need to be considered. In this paper, the transport infrastructure and how transport solution manufacturers influence a sustainable infrastructure is discussed, and a measurement method is presented for measuring the sustainability of transport solutions.

Disclaimer: The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of Volvo Group.

INTRODUCTION

Sustainable transport refers to the wide-ranging subject of vehicles, energy, infrastructure, roads, railways, airways, waterways, canals, pipelines, and terminals that are sustainable. It also involves transport operations and logistics. Over the

© ASCE 2014

years several definitions have been developed to define sustainable transport solutions. Most notably:

The US Federal Highway Administration (FHWA) defines sustainability as a concept that enables decision-makers to make balanced choices around these objectives. The three principles of the "triple bottom line" upon which sustainability is based - social, economic, and environmental - capture the broad range of transportation goals and objectives. In times of diminishing economic and natural resources, using sustainable approaches in transportation infrastructure will help us to continue to enhance quality of life and serve the transportation needs of the present without compromising the ability of future generations to meet their needs (FHWA, 2012).

The Canadian Centre for Sustainable Transportation (CST) defines sustainable transport solutions as sustainable transportation that: 1) allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations. 2) is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy. 3) limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise (CST, 2005).

The University of Washington and CH2M HILL define sustainable transport solutions from the perspective of a transportation designer or contractor. It consists of three key broader ideas are consistent physical constraints or laws of Nature (natural laws), satisfaction of basic human needs and desires (human values), and the idea that roadway projects are best perceived as systems of varying degrees of complexity, interdependence, scale and context. A useful, implementable definition of sustainability for roadway projects must feature these three terms because these ideas are simple to understand and explain to project stakeholders. Importantly, how well a particular project fits these project - specific natural law and human value constraints is a characteristic or trait of that system that is measurable (in terms of quantity and/or quality). This means sustainability on one roadway project can be compared to other roadway projects, and ultimately, sustainability becomes manageable on both short - and long - term time scales. Therefore, sustainability is a characteristic of a system that reflects its capacity to support natural laws and human values (Greenroads Foundation, 2005)

The Natural Step (TNS) defines sustainability as follows (TNS, 2014):

In a sustainable society, nature is not subject to systematically increasing:

1) Concentrations of substances extracted from the earth's crust;

2) Concentrations of substances produced by society;

© ASCE 2014

3) Degradation by physical means;

4) And, in that society, people are not subject to conditions that systemically undermine their capacity to meet their needs.

Professor Elizabeth Deakin simply states that the idea of sustainability has come to be understood as a collective process for considered decision-making and action, and not simply a particular end-state or outcome (Bevan et al., 2011).

Transportation sustainability is usually measured by how effective and efficient a transportation system can be, as well as its environmental impact. Several measurement systems have been globally developed by private and public agencies to quantify sustainability. In specific, a number of these rating agencies or systems target sustainability in transportation. Among the rating systems that have been developed are Sustainable Transportation Access Rating System (STARS), GreenLITES, Greenroads, an American Society of Civil Engineers (ASCE) infrastructure rating system, and FHWA's Sustainable Highways Self-Evaluation Tool.

STARS was created by a non-profit organization established by the City of Portland and developed in partnership with other organizations and consulting firms, including CH2M HILL.

NYSDOTs GreenLITES provides a mandatory checklist of sustainable elements for each project passing through the NY State project assessment system. The North American Sustainable Transportation Council

Leadership in Energy and Environmental Design (LEED) is a suite of rating systems for the design, construction, operation, and maintenance of green buildings, homes and neighborhoods.

The Institute for Sustainable Infrastructure (ISI) developed a sustainable civil infrastructure rating system. ISI is sponsored by ASCE, the American Council of Engineering Companies (ACEC) and the American Public Works Association (APWA). Going beyond the level that LEED requires, ISI takes into account the overall community context as well.

Greenroads was developed by the University of Washington and CH2M HILL, and aimed to rate sustainable roadway design and construction at the project level.

Another system developed by CH2M HILL is the FHWA Sustainable Highways Self-Evaluation Tool. This evaluation tool is unique because unlike the other rating systems, it takes into account the full life-cycle of highways, including system planning, project development, and operations and maintenance of an entire network.

Sustainability, or sustainable development, has been adopted by the United Nations agencies as a supreme goal of economic and social development (UNCED

© ASCE 2014

1992). The most widely cited definition and the one generally recognized as initiating the global consideration of the subject, is from the World Commission on Environment and Development report "Our Common Future".

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

This and most other definitions constitute a normative concept of intergenerational responsibility or fairness. It is also significant that the context of this definition was the issue of economic development and resulting conflicts with the environment. The concept of sustainability balances the right of less advantaged nations to economic development, with the imperative to preserve the resources, especially the environmental resources that future generations will need for their own well-being.

All the definitions and measurements methods presented above are general and do not target transport solution providers. To the contrary, the definition and measurement method are designed for manufacturers of transport products and services. The rest of the paper is organized as follow: first a definition is proposed, and then a measurement methodology is presented. After that the calculation process is explained in details. Finally a case study is presented and conclusions made.

DEFINITION OF SUSTAINABLE TRANSPORT SOLUTIONS

This paper introduces a definition of sustainable transport solutions from a manufacturer point of view. This definition is meant to be the foundation for a manufacturer of transport solutions in making sure that his operations and products are sustainable. It is also the basis for the measurement method that is introduced later in this paper. A transport solution provider would define "Sustainable Transport Solutions" as follows:

A Sustainable Transport Solutions is a way of providing outstanding products and services to the customer without diminishing the ability of future generations to meet their needs. This is accomplished by continuously monitoring the impact of the transport solutions on the economy, the way they affect the environment while having the best interest of the society in mind.

Looking at this definition someone can see that it revolves around three main dimensions, namely economic, environmental, and social dimensions. This is also known as the triple bottom line (TBL or 3BL). In addition, the three categories are sometimes rephrased as profit, people, planet, or denoted as the three pillars.

MEASURING SUSTAINABLE TRANSPORT SOLUTIONS

Hierarchal approach

The proposed measurement method is a hierarchal method that is based on

© ASCE 2014

four levels of measurements. The four levels are as follows: 1) transport solutions, 2) dimensions, 3) components, and 4) indicators.

So starting from top to bottom, each transport solution will have sustainability index that can be split into three dimensions, and each dimension will have several components, while each component will have several indicators:

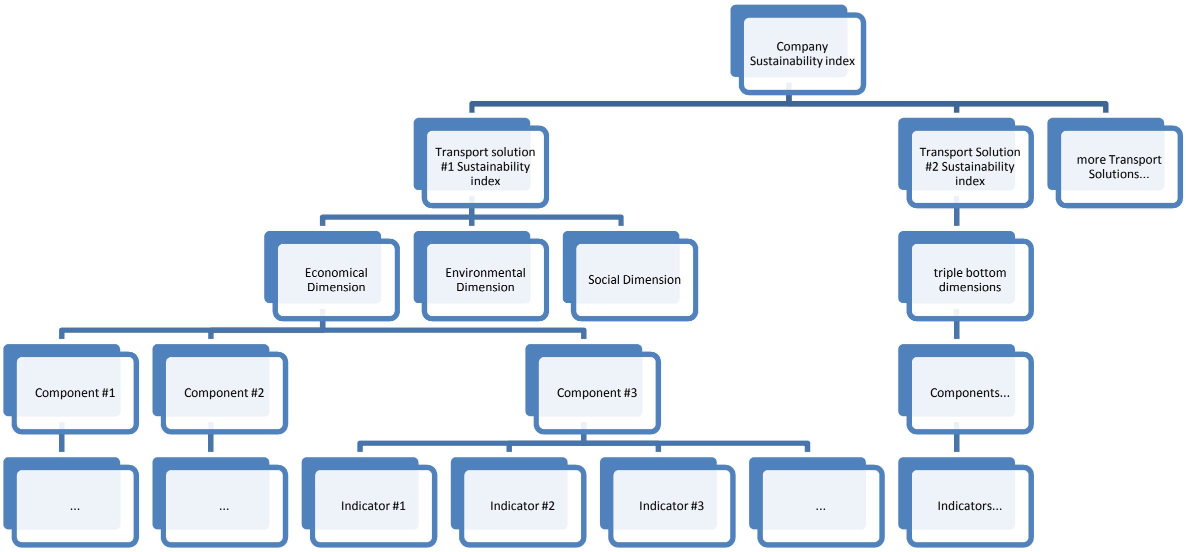


Figure 1 Dimension scores for a number of transport solutions

Scaling measurement data

Indicators are measurements of different aspect of sustainability and are compared against a target value that would indicate its sustainability. Since these indicators cover a wide range of topics and types of measurements it is not possible to compare their values. For instance, an operating margin indicator of 10% cannot be compared to CO_2 emission of 150g/truck. Therefore the data needs to be normalized in order to calculate a common sustainability index that can be used to understand the level of sustainability of transport solutions and companies.

Normalizing

In this paper we adopted a normalizing method known as feature scaling that is commonly used in artificial intelligence methods. It is a process that is used to adjust values measured on different scales to a common scale, resulting in a standardized range of independent variables. For example, data from all indicators can be adjusted to a range of [0, 1]. The general formula is as follow:

$$x_i' = \frac{x_i + min(x)}{max(x) + min(x)}$$

where x_i is an original value of an indicator, x_i' is its normalized value.

© ASCE 2014

$min(x)$ and $max(x)$ are respectively the minimum and maximum possible values of the indicator.

Shifting

The main objective of measuring sustainability is to understand the impact of a transport solution on people, planet, and profit. As different indicators measure different things, their impact can be either a positive impact or a negative one. Therefore, scaling all the data to the same data range is not enough. As a result, after normalizing the data to a range of [0, 1], it is shifted to a negative, positive, or hybrid range:

Indicator	Transformation	Range
Positive Impact	$x_i'' = x_i'$	$0 \leq x_i'' \leq 1$
Negative Impact	$x_i'' = x_i' - 1$	$-1 \leq x_i'' \leq 0$
Hybrid Impact (positive and negative)	$x_i'' = x_i' + \left(\frac{\min(x)}{\max(x) - \min(x)}\right)$	$\left(\frac{\min(x)}{\max(x)-\min(x)}\right) \leq x_i'' \leq 1 + \left(\frac{\min(x)}{\max(x)-\min(x)}\right)$

Weights approach

Not every dimension, component, or indicator has the same impact on sustainability. The proposed process of measuring sustainability assigns a numeric value to each indicator in order to make it comparable to other indicators across different fields.

The process of allocating weights should reflect the relative importance of the indicator. Indicators that have the largest environmental impact should have larger weights. For example, according to a Volvo study, indicators related to operation have a larger impact on the environment compared to indicators related to production or end of life that are considered to have a much smaller impact on the environment. As a result, indicators related to operation would have larger weights.

CALCULATION PROCESS

After the data has been normalized and *shifted* each indicator is multiplied by its corresponding weight and summed up into the component value.

$$\boldsymbol{Component = \frac{1}{N}\sum_{i}^{N} w_i Indicator}$$

Where w_i is the weight for each indicator derived from perceived relevance for sustainability and N is the number of indicators.

© ASCE 2014

$$\boldsymbol{Dimension} = \frac{\mathbf{1}}{\boldsymbol{M}}\sum_{\boldsymbol{k}}^{\boldsymbol{M}}\frac{\mathbf{1}}{\boldsymbol{N}}\sum_{\boldsymbol{i}}^{\boldsymbol{N}}\boldsymbol{w_i Indicator}$$

In order to then calculate the score for each dimension all components associated with that dimension are summed up and divided by the number of components.

$$SI = \frac{1}{3}\sum_{l}^{3}\frac{1}{M}\sum_{k}^{M}\frac{1}{N}\sum_{i}^{N}w_i Indicator$$

The sustainability score for a certain transport solution is then calculated by averaging each dimension score, this gives an overview on how sustainable in total the transport solution really is. In a similar fashion the sustainability score for a company or a certain brand can be calculated through simply averaging the sustainability score for each transport solution.

$$Company_{SI} = \frac{1}{L}\sum_{j}^{L}\frac{1}{3}\sum_{l}^{3}\frac{1}{M}\sum_{k}^{M}\frac{1}{N}\sum_{i}^{N}w_i Indicator$$

Here L is the number of transport solutions in a company's brand portfolio. The SI can also be used to compare different transportation modes against each other through the same logic.

CASE STUDY

A case study to verify the calculation process has been conducted using simulated data for a number of different transport solutions. The simulations of the weight for the indicators were based on the total lifecycle impact for the transport solutions used in the study. Greater weights were used for indicators pertaining to operation whereas smaller weights were used for indicators related to end of life and production.

© ASCE 2014

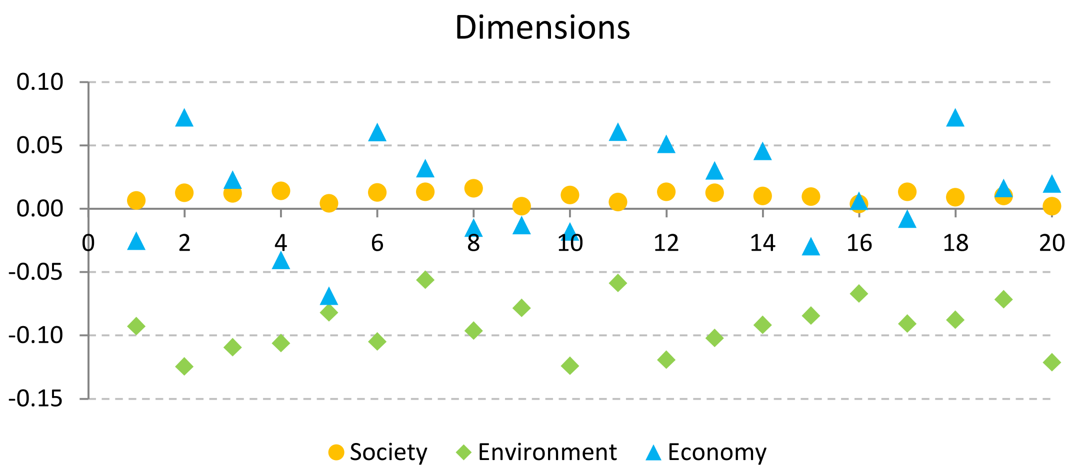


Figure 2 Dimension scores for a number of transport solutions

After summing up the different component scores for the transport solutions it is possible to see how they perform against each other as well as the performance of each dimension. Figure 2 shows the dimension scores for the simulated transport solutions, in this case most of the simulated transport solutions have a strongly negative impact on sustainability in the environmental dimension, however once averaged into a total sustainability score we can see that some transport solutions can have a positive impact on overall sustainability.

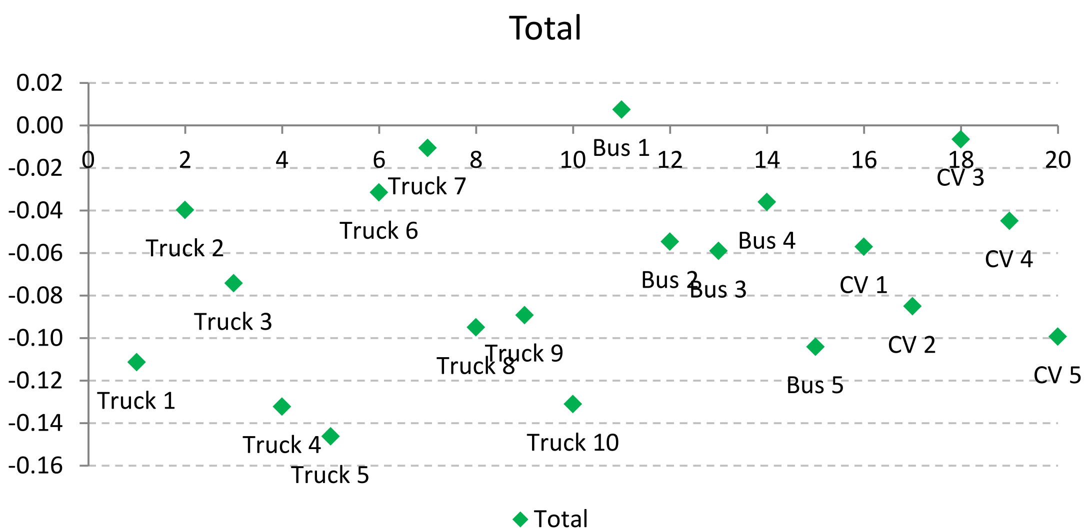


Figure 3 Product scores for a number of transport solutions

The total sustainability score gives a quick overview on the sustainability of each transport solution and hints to what solutions a company might need to focus

© ASCE 2014

its sustainability measures in order to be the most productive or have the greatest output.

Creating a benchmark for different transport solution providers is also possible at this stage and can be of value when a company is performing a competitor analysis, a governing body needs to assess the different actors present in the market, or even comparing different transportation modes in order to gleam their overall sustainability.

Case Study Data

	Impact	Target	Weight	Mean	Max	Min	Truck 1	Truck 2	Etc…
Economy									
Corporate financial sustainability									
Total debt to equity ratio	Both	25%	0.05	0.0	1	-1	0.1	0.0	…
Operating margin	Both	5%	0.05	0.0	1	-1	0.0	-0.1	…
Corporate research	Positive	0%	0.05	0.0	1	0	0.1	0.1	…
GDP contribution									
Contribution to GDP Growth	Positive	0%	0.9	0.1	1	0	0.0	0.1	…
Customer finances									
Running costs	Negative	0%	0.1	52.7	99.4	0	89.5	16.6	…

	Impact	Target	Weight	Mean	Max	Min	Truck 1	Truck 2	Etc…
Environment									
Energy									
Fossil Electricity consumption	Negative	0%	0.05	4.3	9.1	0	9.1	1.2	…
Water									
Net water consumption	Negative	0	0.05	4.9	9.7	0	5.9	4.2	…
Emissions to water	Negative	0	0.05	0.4	0.7	0	0.6	0.7	…
Factory Emissions									
NOx	Negative	0	0.05	49.5	92.5	0	34.9	46.6	…
HC	Negative	0	0.05	53.0	97.4	0	25.7	44.0	…
CO	Negative	0	0.05	43.9	99.2	0	13.5	99.2	…
CO2	Negative	0	0.05	50.0	97.0	0	42.3	84.6	…
PM	Negative	0	0.05	57.1	98.3	0	79.8	73.2	…
Truck Emissions (lifetime)									
NOx	Negative	0	0.9	50.9	96.8	0	75.1	92.9	…
SO	Negative	0	0.9	54.9	97.3	0	32.6	97.3	…
CO2	Negative	0	0.9	44.3	89.7	0	53.4	68.5	…
Waste									
Hazardous waste	Negative	0	0.05	4.6	9.1	0	3.0	3.2	…
Waste	Negative	0	0.05	0.4	1.0	0	0.2	0.2	…
Sodium	Negative	0	0.05	0.5	2.1	0	0.4	1.2	…
Recycle									

© ASCE 2014

Recyclable materials	Positive	100%	0.05	0.6	100	0	0.5	0.5	...
Noise									
Noise level (plant)	Negative	30	0.05	51.0	98.0	0	35	41	...
Noise level (Vehicle)	Negative	30	0.18	52.9	95.0	0	80	84	...

	Impact	Target	Weight	Mean	Max	Min	Truck 1	Truck 2	Etc...
Society									
Responsibility									
CSR Certified Suppliers	Positive	100%	0.05	0.5	100	0	0.9	0.1	...
Employees									
Employee engagement	Positive	100%	0.05	0.5	100	0	0.7	0.6	...
Temporary employees	Negative	0	0.05	0.0	100	0	0.1	0.0	...
Female employees (leaders)	Positive	50%	0.015	0.6	100	0	0.9	0.7	...
Female employees (board)	Positive	50%	0.015	0.5	100	0	0.2	0.4	...
Female employees	Positive	50%	0.015	0.5	100	0	0.7	0.2	...
Fatality Rate	Negative	0	0.05	0.3	1.0	0	0	0	...
Nonfatal injuries rate	Negative	0	0.05	42.7	98.0	0	63	22	...
Community engagement									
Charitable donations	Positive	0	0.05	6.7	10.0	0	5	8	...

CONCLUSION

In this paper, the transport infrastructure and how transport solution manufacturers influence a sustainable infrastructure is discussed, and a measurement method is presented for measuring the sustainability of transport solutions. Being able to measure sustainability for transport solutions can have a major impact on how a company operate. Using the approach that is proposed in this paper can give a hint as to where a company needs to focus its efforts in order to have the best return on invested time and resources. The proposed method allows a comparison of how sustainable different transport solutions and companies are. Furthermore, it provides manufacturers of transport solutions an awareness of where they stand as far as sustainability is concerned. Finally, it gives the necessary stakeholders the opportunity to get involved in setting weights for indicators and have a clear understanding of the impact of their contributions.

REFERENCES

Greenroads Foundation. (2011). "Greenroads™ Version 1.5 Manual." < https://www.greenroads.org/1184/manual.html > (March 14, 2014)

FHWA. (2012). "INVEST _ Economic - Social - Environmental _ Sustainable Highways Self-Evaluation Tool." United States Department of Transportation, Federal Highway Administration (FHWA), <https://www.sustainablehighways.org/INVEST_1.0_Compendium_Web.pdf> (October, 2012)

© ASCE 2014

CST. (2005). "Defining Sustainable Transportation." <http://cst.uwinnipeg.ca/documents/Defining_Sustainable_2005.pdf> (March 31, 2005)

TNS (2014). "A Science-Based Definition of Sustainability." The Natural Step (TNS)< http://www.naturalstep.org/the-system-conditions >. (March 14, 2014)

Timothy A. Bevan, Michael Culp, Constance M. Hill Galloway, Heather Holsinger, and Lisa Reid. (2011) "Federal Highway Administration Infrastructure Voluntary Evaluation Sustainability Tool (INVEST)" ICOET 2011 Proceedings.

Volvo Group. (2012). Volvo Group Environmental Data Report 2012. Gothenburg: Volvo Group.

United Nations World Commission on Environment and Development. (1987). Our Common Future. Oxford University Press.

© ASCE 2014

Introducing Sustainability into the Engineering Curriculum

Cliff I. Davidson[1] and Miriam Heller[2]

[1] Syracuse Center of Excellence in Environmental and Energy Systems and Department of Civil and Environmental Engineering, Syracuse University, 151 Link Hall, Syracuse, NY 13210; email: davidson@syr.edu
[2] MHITech Systems; Distinguished Visiting Scholar at Stanford University mediaX; and Zanvyl Krieger School of Arts and Sciences, Johns Hopkins University; email: heller@mhitech.com

ABSTRACT

In response to problems such as decreasing availability of resources, changing climate, and the need to minimize wastes, engineers are being asked to incorporate new constraints into their decision-making. The result is the emerging field of sustainable engineering which is changing the practice of engineering worldwide. Several efforts are underway to enable more efficient development, sharing, and use of sustainable engineering educational materials at universities. Here we discuss a couple of those efforts taking place in the U.S., namely the activities of the Center for Sustainable Engineering operated by a consortium of universities, and plans to develop a community-oriented web platform to serve as a repository for educational materials.

INTRODUCTION

We are in the midst of major political, economic, and social changes within the U.S. and abroad. Globalization is increasing and is certain to continue. Rising population and urbanization are bringing new challenges. Standards of living in many countries are improving, a welcome change but one that demands greater use of resources while putting more people and assets in harm's way. These changes have profound implications on how engineers will serve society in the coming decades.

Perhaps the most important challenge facing engineers is the need to incorporate sustainability constraints into every engineering project. Human influence on the functioning of the earth's natural systems is significant and continually increasing. Since we depend on the world's ecology, climate, and geologic systems for our survival, it is imperative that we as engineers understand how our decisions affect these systems and the services they provide.

Until recently, education and training of engineers has not included sustainability constraints in the curriculum. This is a serious problem as we continue to educate engineers for the challenges of the twenty-first century. Numerous institutions and departments have stepped up to meet these needs. According to the 2008 benchmarking study by Allen et al. (2008), more than 16 percent or 218 department heads, from over

© ASCE 2014

1300 accredited engineering departments contacted, reported that sustainable engineering was either offered as a self-contained course or as content integrated into existing courses. However, education of engineers involves thousands of programs worldwide, and there are no coordinated efforts to enable change in engineering education on the scale necessary.

In this paper, we discuss two specific efforts designed to accelerate the pace of change in engineering education. The first is the Center for Sustainable Engineering (CSE), a consortium of universities in the U.S. that has attempted to assist engineering educators in their efforts to incorporate sustainability into engineering classes. The second is the Sustainable Engineering Education Digital Repository (SEEDR), a proposed web platform to serve the needs of the engineering education community for educational and assessment materials in courses worldwide.

THE CENTER FOR SUSTAINABLE ENGINEERING

The CSE was founded at Carnegie Mellon University in 2005. Several schools have participated as consortium members since then, including the University of Texas at Austin, Arizona State University, Georgia Institute of Technology, and most recently Syracuse University, which is currently the lead institution. The mission of the CSE is to assist engineering educators in efforts to infuse concepts of sustainability into college courses in all branches of engineering. These concepts include evolving principles for economic, environmental, and social sustainability, where these three dimensions are necessary to maximize chances that the needs of future generations can be met.

The CSE has engaged in three activities since its inception. First, the Center has conducted workshops for engineering faculty members on incorporating sustainability into engineering courses. Second, the Center has hosted a peer-reviewed Electronic Library of educational materials written by workshop attendees. Finally, the Center has conducted a benchmarking study of the status of sustainable engineering in courses and programs, an effort spearheaded by the University of Texas at Austin (Allen et al., 2008; Murphy et al., 2009). The benchmark study is available on the CSE website www.csengin.org. This section of the paper on the CSE discusses the workshops and the Electronic Library.

CSE Workshops

The Center has conducted several workshops for engineering professors to help them enhance the sustainability content of their courses. These include two 2-day workshops per year in 2006, 2007, 2009, 2011, and 2012, one 2-day workshop in 2013, and two half-day sessions at meetings of the Association of Environmental Engineering and Science Professors in 2011 and 2013. There was also a planning meeting to discuss the long-term goals of the Center in 2008. Nearly 300 faculty members have participated in the 2-day workshops, with another 100 in the AEESP sessions. All of the data in this paper refer to those who have attended the 2-day workshops, but not the AEESP sessions.

© ASCE 2014

Information on the participants of the regular 2-day workshops is shown in Table 1. The breakdown of the departments represented in the "Other" column is shown in Table 2.

Table 1. Number of participants at the CSE workshops for each year in which workshops were held.

Year	Male	Female	Civil Engineering M+F	Mechanical Engineering M+F	Other M+F
2006	45	17	36	7	19
2007	39	19	36	6	16
2009	35	20	27	11	17
2011	34	19	36	6	11
2012	29	11	18	7	15
2013	17	13	17	3	10
Total	199	99	170	40	88

Faculty from Civil Engineering or Civil & Environmental Engineering departments had the largest representation at every workshop. This category also included a small number of Architectural Engineering and Construction Engineering departments. Faculty from Mechanical Engineering had the second largest contingent in most years; this category also included Aeronautical Engineering and Manufacturing Engineering departments.

Table 2. Number of participants in each discipline for the 88 participants in the "Other" column of Table 1.

Discipline	# Participants
Bio-engineering	4
Chemical Engineering	19
Electrical Engineering	5
Industrial Engineering	20
Materials Engineering	5
General Engineering	24
Miscellaneous	11
Total Participants	88

For the categories listed in Table 2, Chemical Engineering also included Polymer and Fiber Engineering. The Industrial Engineering category also included Systems Engineering and Sustainable Engineering. Materials Engineering included Materials Science and Engineering, Materials Science, and similar names. General Engineering included a number of departments with names such as Engineering, Engineering Technology, and Engineering Science. The Miscellaneous category included Agricultural, Geological, Mining, Petroleum, and other types of Engineering.

© ASCE 2014

The participants of the CSE workshops represented over 100 universities around the U.S., and some universities in Canada and a few other countries. The locations of those institutions in the continental U.S. and Canada are shown in Figure 1.

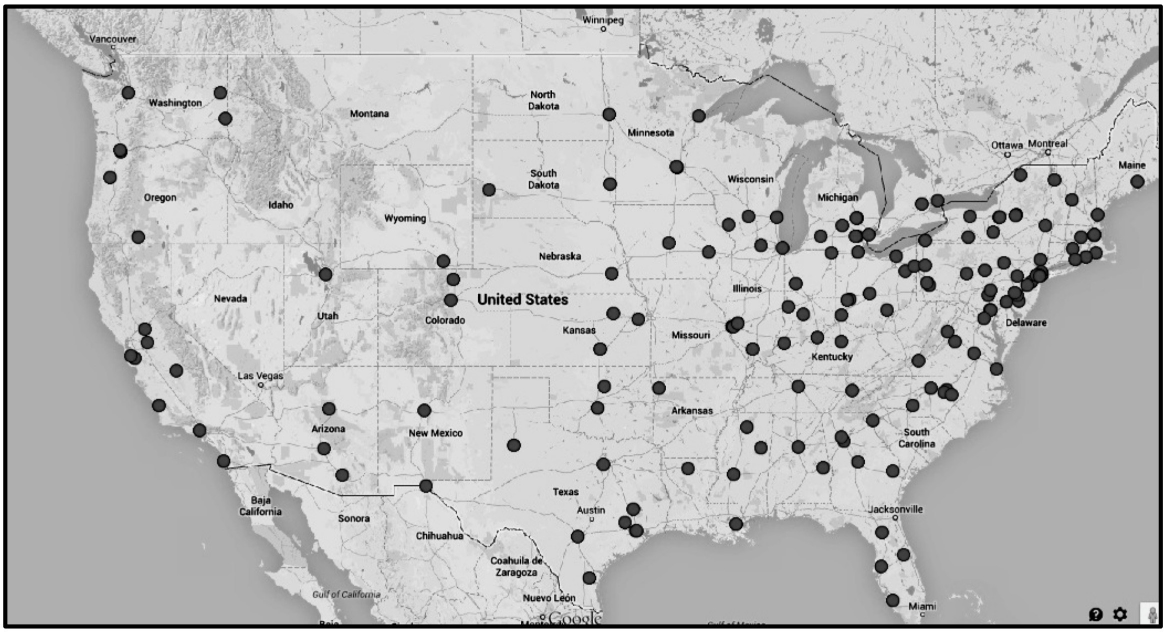


Figure 1. Locations of universities with faculty members who have attended CSE workshops.

The workshops included sessions such as defining sustainable engineering, metrics of sustainability, sources of educational materials, pedagogy in teaching sustainable engineering, and discussion of key content areas like life cycle assessment, industrial ecology, and design for sustainability. The material was presented in plenary discussions as well as breakout groups with specified activities.

Evaluations of workshops were conducted using the following four-point scale:
1 = not valuable
2 = minimally valuable
3 = moderately valuable
4 = very valuable

Scores of all workshop sessions were 3.2 $\pm$ 0.3 in 2006, 3.3 $\pm$ 0.3 in 2007, 3.4 $\pm$ 0.2 in 2009, 3.5 $\pm$ 0.2 in 2011, 3.5 $\pm$ 0.2 in 2012, and 3.5 $\pm$ 0.1 in 2013. The scores show successive improvement as more experience was gained in organizing the workshops. The overall average score for individual workshop sessions was 3.4 with N = 4370 (average 14.7 sessions per workshop x 27 participants x 11 workshops).

The evaluations also included several questions on the extent to which the goals of the workshops were achieved, and on the overall quality of the workshop. For all 298 participants, examples of the results are as follows:

To what extent did the workshop facilitate the sharing of ideas for incorporating sustainable engineering into classes? Score = 3.8

To what extent did the workshops motivate you to expand your teaching in sustainable engineering? Score = 3.6

Overall quality of the workshop: Score = 3.7

Suggestions for improvement of the workshops were solicited on the evaluation forms after every workshop, and a number of those suggestions were incorporated into later workshops.

CSE Electronic Library

Educational modules are solicited from the participants of the workshops for posting on the CSE website. There is no charge to the author for posting a module, and the module is open access.

To enable the modules to be of maximum benefit, all submissions are required to contain significant written technical content, and all are sent out for peer review. Modules must include at least several pages of written documentation, beginning with an introduction to the topic(s) of interest, followed by a detailed technical discussion, which constitutes the body of the module and may include figures, tables, and equations in addition to text. A complete bibliography of references is required. Supporting documents often include homework problems, class project descriptions, datasets, visual aids such as MS PowerPoint slides, and other materials. However, these supporting documents do not constitute a module by themselves. A detailed discussion with appreciable technical content is required.

As with a peer-review journal, authors are required to respond to reviewers' comments and either defend their position or revise the manuscript. Ultimately, the module is either accepted or rejected by the editor, and the final manuscript with supporting documents is posted on the CSE website.

There are currently 60 modules on the website, with many more under review. The modules are indexed by author, keywords, discipline, publication year, audience, ABET outcome, level of difficulty, and type of learning resource.

A DIGITAL REPOSITORY TO SERVE THE SUSTAINABLE ENGINEERING COMMUNITY

The establishment of the CSE coincides with a burgeoning online presence in terms of learning and content, the Open Educational Resources movement promising to transform

© ASCE 2014

the web into a library of global courses, and innovations from research on new instructional methods. The time is ripe to take advantage of these rapid advances to catalyze a community for sustainable engineering education that can more efficiently produce a global workforce prepared to move toward sustainability.

Ubiquitous Online Content and Learning

The growth in online learning represents an opportunity to gather and organize existing content as well as develop new content in support of expanding demands for sustainable engineering education. Unlike core engineering courses, criteria for accreditation relevant to sustainable engineering were only recently introduced. Student outcomes specified as Criteria 3 under General Criteria for Baccalaureate Level Programs now include “an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability” (ABET 2013). Graduates from architectural and related engineering programs are expected to reach a design level that “considers fundamental attributes of building performance and sustainability” (ABET 2013, pg. 11). Curricular criteria for environmental and related engineering programs aim to prepare graduates to “design environmental engineering systems that include considerations of risk, uncertainty, sustainability, life-cycle principles, and environmental impacts” (ABET 2013, pg. 7).

This new mandate aside, a rich, diverse and distributed sustainable engineering content is waiting to be tapped. The results from the 2008 benchmarking survey, the nearly 300 participants in CSE workshops, and funded research programs in sustainability, energy efficiency, and climate change leave little doubt that there is a rich body of sustainable engineering educational resources. Yet issues remain in locating these resources, accessing them, determining their validity, and obtaining authorization to use them, making it difficult to take advantage of the wealth of information available.

In the decade since CSE’s founding in 2005, online educational resources have become ubiquitous, and the use of learning management systems such as Blackboard and e-learning have skyrocketed. Degree-granting postsecondary institutions reported that more than 7.1 million students or 33.5 percent of total student enrollment had taken at least one online course in the 2011-2012 academic year. This reflected a stunning online growth rate of 124 percent compared to 22 percent growth in total enrollment since 2005 (Allen and Seaman, 2014).

Massive open online courses (MOOCs) were recognized as a game-changer in online learning when the New York Times dubbed 2012 the “Year of the MOOC” (Pappano 2012). Most often offered through consortia of top universities, MOOCs typically attract tens of thousands of registrants. The European Commission (EC) counted 2,625 MOOCs as of June 2014, up 327 percent from June 2013 based on 10 EC and 22 non-EC providers (Open Education Europa, 2014). The main U.S. players – Coursera, Udacity, edX, Canvas Network, Novoed, and others – offer more than 1000 courses.

© ASCE 2014

Several MOOCs already have content applicable to sustainable engineering courses; some examples are shown in Table 3. Other MOOCs contain supplementary topics for sustainable engineering material including ethics, business, policy, financing, and pedagogical topics such as assessment and analytics.

Table 3. Examples of MOOCs with Content Relevant to Sustainable Engineering

Course Title	Provider
Introduction to Sustainability	Coursera
Global Sustainable Energy: Past, Present and Future	Coursera
Climate Change in Four Dimensions	Coursera
Wheels of Metals: The Global Metals Challenge	Coursera
How Green is this Product? An Introduction to Life Cycle Environmental Assessment	Coursera
Sustainable Product Development and Manufacturing	Novoed
Sustainable Energy Innovation	Canvas Network
Sustainability in Practice	Coursera
The Age of Sustainable Development	Coursera
Sustainability of Food Systems: A Global Life Cycle Perspective	Coursera
Sustainable Agricultural Land Management	Coursera
Supply Chain Management: A Learning Perspective	Coursera

MOOCs, despite their name, vary in terms of openness as defined by their "terms of use". They often retain proprietary intellectual property rights, such as prohibiting copying or modifying the material, e.g., as stated in Coursera's *Permission to Use Materials*.

The open educational resources (OER) movement, however, is leading the way to new, flexible licensing options in which some or none of the rights are reserved. The Khan Academy (https://www.khanacademy.org), MIT OpenCourseware (http://ocw.mit.edu/), and Washington's Open Course Library (http://opencourselibrary.org) all offer open courses. Another example is Coursera's Introduction to Sustainability MOOC, which is based on a free, online textbook "Sustainability: a Comprehensive Foundation", an OER, licensed through the Creative Commons (Theis and Tomkin 2014).

Research-based Instructional Methods and Assessment

The growing literature on innovation in instructional methods and assessment presents another opportunity for faculty development. Twelve national and regional Engineering Education Research and Teaching Centers and many more campus centers participate in engineering education research and/or provide teaching, learning, outreach, assessment, and faculty development. However, Froyd et al. (2013) found that research-based instructional strategies such as service- and problem-based learning are not diffusing into the academy as rapidly as would be expected given substantial evidence of their efficiency. Some key barriers to applying these strategies are preparation time and the amount of class time they consume.

© ASCE 2014

Workshop on Sustainable Engineering Education

To exploit these innovations in teaching and research, a workshop for the sustainable engineering community has been planned for August 5-6, 2014. Key goals of the workshop are to:

1. Expose the community to the benefits of a sustainable engineering education digital repository (SEEDR) to improve teaching efficiency;
2. Illustrate state-of-the-practice online educational resources as well as instructional design and assessment methods to improve teaching effectiveness; and
3. Solicit and assess the community's requirements and preferences, and identify barriers that must be surmounted to ensure the usefulness, usability and use of the repository.

A Sustainable Engineering Education Digital Repository: the SEEDR Vision

SEEDR is envisioned as a strategic opportunity to coalesce the sustainable engineering education community around several activities. The proposed web platform should make it possible to contribute and share educational resources, increase teaching efficiency and learning effectiveness, reduce costs and environmental impacts associated with physical course material, intelligently satisfy new sustainable design accreditation requirements, and build capacity by preparing practicing engineers as well as engineers engaged in research to solve the sustainability challenges of our time.

SEEDR, accessible through a community web portal, would accommodate a range of learning resources. Some examples are textbooks, lecture materials, lesson plans, slides, videos, lab exercises, homework problems, simulators, and models. Online resources facilitate change in content, e.g., resulting from detailed analytics to optimize use and improve content and keep the materials up to date in rapidly evolving disciplines.

Digital learning repositories have matured over the past decade, especially due to the increasing use of learning management systems and learning content management systems. The widespread use of these systems is linked to maintaining student grades online in compliance with the Family Educational Rights and Privacy Act. Key to the acceptance and use of these repositories is meeting the functional requirements of potential users. Basic functions were defined by the IMS Global Learning Consortium (2014) and include search, gather, browse, configure, publish, store, expose, and deliver.

Several communities that share educational content can provide insight into attributes for success, and some of these communities will be represented at the workshop. These include 1) nanoHUB, a state-of-the-art cyberlearning architecture that buttressed the growth of a nascent nanoelectronics community in 2004 and now counts over 325,000 annual users per year, an estimated 40 percent of which tap nano-focused educational materials (nanoHUB, 2014); 2) Theis and Tomkin's (2014) free, wiki-based textbook "Sustainability: a Comprehensive Foundation"; 3) Masanet's (2014) Coursera MOOC "How Green is This Product? An Introduction to Life Cycle Environmental Assessment" which attracted over 10,000 registrants in its internet debut in January 2014 (Northwestern Engineering, 2013); 4) Merlot II's free and open peer-reviewed online

© ASCE 2014

teaching and learning materials and faculty-developed services contributed and used by an international education community (Merlot II, 2014); and 5) Pearson's Equella digital repository, the Pearson Learning Studio, online learning platform and OpenClass online learning environment, which are closely linked to Pearson texts and enable personalized composition of teaching materials and learning (Pearson, 2014).

Survey to Capture User Requirements

As a service-oriented repository, SEEDR should provide features and functions sought by the potential users in the sustainable engineering education community. By webcasting the workshop, the greater community will be included and surveyed for their preferences along with the in-person participants. Standard capabilities will be identified, reviewed and assessed.

SUMMARY

Global sustainability and now accreditation requirements highlight the importance of introducing sustainability into the engineering curriculum. Creative ways are needed to exploit the extensive, non-uniform and distributed educational resources that have evolved over the past few decades. Targeted training like workshops offered through the CSE have created a shared vision of and material on sustainable engineering across disciplines. The upcoming workshop and surveys will inform the community of additional technologies and research-based methods to help instructors bring sustainability into their engineering curricula efficiently and effectively. The workshop and surveys will also verify interest in solidifying the community and creating shared resources for sustainable engineering content to change the curricula more systematically. A final report of the workshop will describe design requirements and long-term options for sustainability of the web portal to serve the sustainable engineering education community.

ACKNOWLEDGMENTS

The authors acknowledge the support of the U.S. National Science Foundation through grant CBET-1440208.

REFERENCES

ABET Engineering Accreditation Commission. (2013). Criteria for Accrediting Engineering Programs: Effective for Reviews During the 2014-2015 Accreditation Cycle, ABET: Baltimore, MD. Retrieved June 18, 2014 from http://www.abet.org/uploadedFiles/Accreditation/Accreditation_Step_by_Step/Accreditation_Documents/Current/2014_-_2015/E001%2014-15%20EAC%20Criteria%203-13-14(2).pdf.

Allen, D. T., Allenby, B. R., Bridges, M., Crittenden, J. C., Davidson, C. I., Hendrickson, C. T., Matthews, H. S., Murphy, C. F., and Pijawka, D. (2008). "Benchmarking Sustainable Engineering Education," Final Report for EPA Report X3-83235101-0,

© ASCE 2014

December 31, 2008. Available at http://www.csengin.org/csengine/sub.html?skuvar=147.

Allen, I. E. and Seaman, J. (2014). Grade Change: Tracking Online Education in the United States, Babson Survey Research Group and Quahog Research Group, LLC: Wellseley, MA, February 2014, retrieved June 16, 2014 from http://www.onlinelearningsurvey.com/reports/gradechange.pdf.

Coursera. (n.d.). Terms of Use. Retrieved June 18, 2014 from https://www.coursera.org/about/terms.

Froyd, J., Borrego, M., Cutler, S., Henderson, C., and Prince, M. (2013). Estimates of Use of Research-Based Instructional Strategies in Core Electrical or Computer Engineering Courses, IEEE Transactions on Education, 56 (4), 393-399.

IMS Global Learning Consortium. (2014). IMS Digital Repositories Specification Version 1.0 - Final Specification, Retrieved June 19, 2014 from http://www.imsglobal.org/digitalrepositories/.

Masanet, E. (2014). *How Green is This Product? An Introduction to Life Cycle Environmental Assessment,* Coursera, https://www.coursera.org/course/introtolca.

Merlot II. (2014). Multimedia Educational Resource for Learning and Online Teaching, http://www.merlot.org/merlot/index.htm.

Murphy, C. F., Allen, D. T., Allenby, B. R., Crittenden, J. C., Davidson, C. I., Hendrickson, C. T., and Matthews, H. S. (2009).“Sustainability in Engineering Education and Research at U.S. Universities,” Environmental Science and Technology, 43 (15), 5558-5564.

nanoHUB. (2009). nanoHub.org: an NCN project. Retrieved 7/3/2014 from http://www.nanohub.org.

Northwestern Engineering. (2013). *McCormick Launching New MOOCs in 2014*. Retrieved June 18, 2014 from http://www.mccormick.northwestern.edu/news/articles/2013/12/mccormick-launching-new-moocs-in-2014.html.

Open Education Europa. (2014, February 6). *European MOOCs Scoreboard, European Commission*. Retrieved on June 16, 2014 from http://www.openeducationeuropa.eu/en/european_scoreboard_moocs.

Pappano, L. (2012, November 2). The Year of the MOOC, The New York Times Online. Retrieved on June 16, 204 from http://www.nytimes.com/2012/11/04/education/edlife/massive-open-online-courses-are-multiplying-at-a-rapid-pace.html?pagewanted=all.

Pearson. (2014). Digital Content Repository. Retrieved June 18, 2014 from http://www.pearsonlearningsolutions.com/academic-executives/digital-content-repository.php.

Theis, T. and Tomkin, J. (Eds.) (n.d.). *Sustainability: A Comprehensive Foundation*. Retrieved June 18, 2014 from http://www.earth.illinois.edu/sustain/sustainability_text.html.

© ASCE 2014

Decision Support Model for Integrated Intervention Plans of Municipal Infrastructure

H. Elsawah[1], M. Guerrero[2], and O. Moselhi[3]

[1] Department of Building Civil & Environmental Engineering, Concordia University, Montreal, Canada, 1455 de Maisonneuve Blvd. West, Montreal, Québec, CANADA, H3G 1M8, PH (514) 848 2424 Ext. 7035, FAX (514) 848 7969, email: helsawah@hotmail.com

[2] Project Engineer, City of Montreal, Québec, CANADA, PH (514) 620 6884, FAX (514) 620 6902, email: mguerrero@ville.montreal.qc.ca

[3] Department of Building Civil & Environmental Engineering, Concordia University, Montreal, Canada, 1455 de Maisonneuve Blvd. West, Montreal, Québec, CANADA, H3G 1M8, PH (514) 848 2424 Ext. 3190, FAX (514) 848 7969, email: Moselhi@encs.concordia.ca

ABSTRACT

This paper describes a model designed to facilitate the decision making process for corridor rehabilitation of municipal assets. The proposed model comprises four main modules encompassing identification of corridor segments, risk assessment of individual asset networks and integrated risk assessment to identify critical corridor segments and set priorities for intervention plans. In general, risk assessment requires integration of the criticality of the asset condition and the consequences of failure values to prioritize intervention plans. Each asset network was evaluated with respect to thirteen economic, social, and environmental factors using a weighted scoring system. The criticality index of each asset was developed by combining the consequence of failure index with the condition rating index. The integrated risk index for network segments was calculated by integrating the three criticality indices of the individual assets. A case study, from one of the 19 boroughs within the metropolitan area of the City of Montreal in Canada, was used to illustrate the developed modules and their respective functions. The results indicated strong positive relationship between the integrated risk index and the criticality indices of the three networks. It also shows that the model successfully represents the integrated criticality index for the combined water, sewer and road segments using their criticality indices as the coefficient of determination R^2 was 0.9656. The implementation of the proposed model on the case study enabled condition rating of integrated segments into five main levels of criticality. The developed model is expected to assist municipal engineers and decision makers to prioritize inspections, rehabilitation and replacement decisions and optimize budget allocation and resource usage.

Keywords: Decision support model, decision making, integrated municipal asset management, risk analysis, coefficient of failure, water, sewer, road network.

© ASCE 2014

INTRODUCTION

Infrastructure assets deteriorate over time. According to the ASCE's Report Card for America's Infrastructure in 2013 (ASCE 2013 Report Card), water, wastewater and road networks had the lowest condition scores of "D"; indicating near failure condition. The report also showed that water pipes are more than 100 years old and that much of the water infrastructure is nearing the end of its useful life. There are an estimated 240,000 water main breaks per year in the United States. Assuming every pipe would need to be replaced, the cost over the coming decades could reach more than $1 trillion, according to the American Water Works Association (AWWA). It was also shown that the problems associated with aging wastewater systems are daunting. Capital investment needs for the American's wastewater and storm water systems are estimated to total $298 billion over the next 20 years. Moreover, 32% of America's major roads are in poor condition. Currently, the Federal Highway Administration (FHWA) estimates that $170 billion in capital investment would be needed on an annual basis to significantly improve the condition and performance of the nation's road network.

In practice, infrastructure assets are typically managed with little or no consideration to their integration. Generally, a city describes a project as separate entity for roads, sewers or water mains. Cities also use priority based ad-hoc scheduling driven by the condition rating of the individual asset. Practically, all three assets can be part of the same right-of-way at the same time. However, they are rarely considered together in a fully integrated decision-making process.

Considerable research was conducted concerning condition assessment of different municipal infrastructure assets (Al-Barqawi and Zayed 2008, Rajani et al. 2006, Ruwanpura et al. 2004, Yan and Vairavamoorthy 2003, Baur and Herz 2002, Bandara and Gunaratne 2001), risk analysis (Salman and Salem 2012, Fares and Zayed 2009, Kleiner et al. 2006, Sadiq et al. 2004, Christodoulou et al. 2003) and decision analysis (Rogers and Grigg 2006, Shahata and Zayed 2009). However, most of these models focused on developing models to support individual infrastructure. Recently, Several efforts have been made to develop integrated infrastructure models. These models can also be classified into two main categories: (1) models for relationships within individual network asset (Gomes 1990, Teng and Tzeng 1996, Iniestra and Gutierrez 2009) and (2) models for relationships among multiple network assets (Rinaldi et al. 2001, Dudenhoeffer et al. 2006, Dueñas-Osorio et al 2007, Halfawy 2008, Chen et al. 2009, Islam and Moselhi 2011, Shahata and Zayed 2009).

Although a significant number of researchers have focused on developing risk assessment models, determining the consequences of failure and incorporating this information to prioritize assets has not been fully examined (Salman and Salem 2012). One of the reasons is due to the uncertainty and difficulty of determining the consequences of failures in terms of monetary values. Instead, municipalities may develop consequences of failure indices in order to make comparisons and identify areas that face a higher impact due to potential failure. Consequences of failure indices aim at transferring qualitative and quantitative risk factors into a point system based on expert opinion.

© ASCE 2014

This paper presents a new model that aims at providing an integrated condition rating suitable for prioritizing corridor intervention plans. The model accounts for integrating water, sewer, and road networks. For analysis of results, the proposed model was applied on one the boroughs of the metropolitan area of the city of Montreal.

PROPOSED MODEL

Figure 1 depicts the main components and main steps of the proposed model. It comprises four main modules designed to perform four functions: (1) identification of corridor segments; (2) risk assessment for individual networks; (3) risk assessment for the integrated corridor segments; and (4) optimization of intervention plans for the entire network.

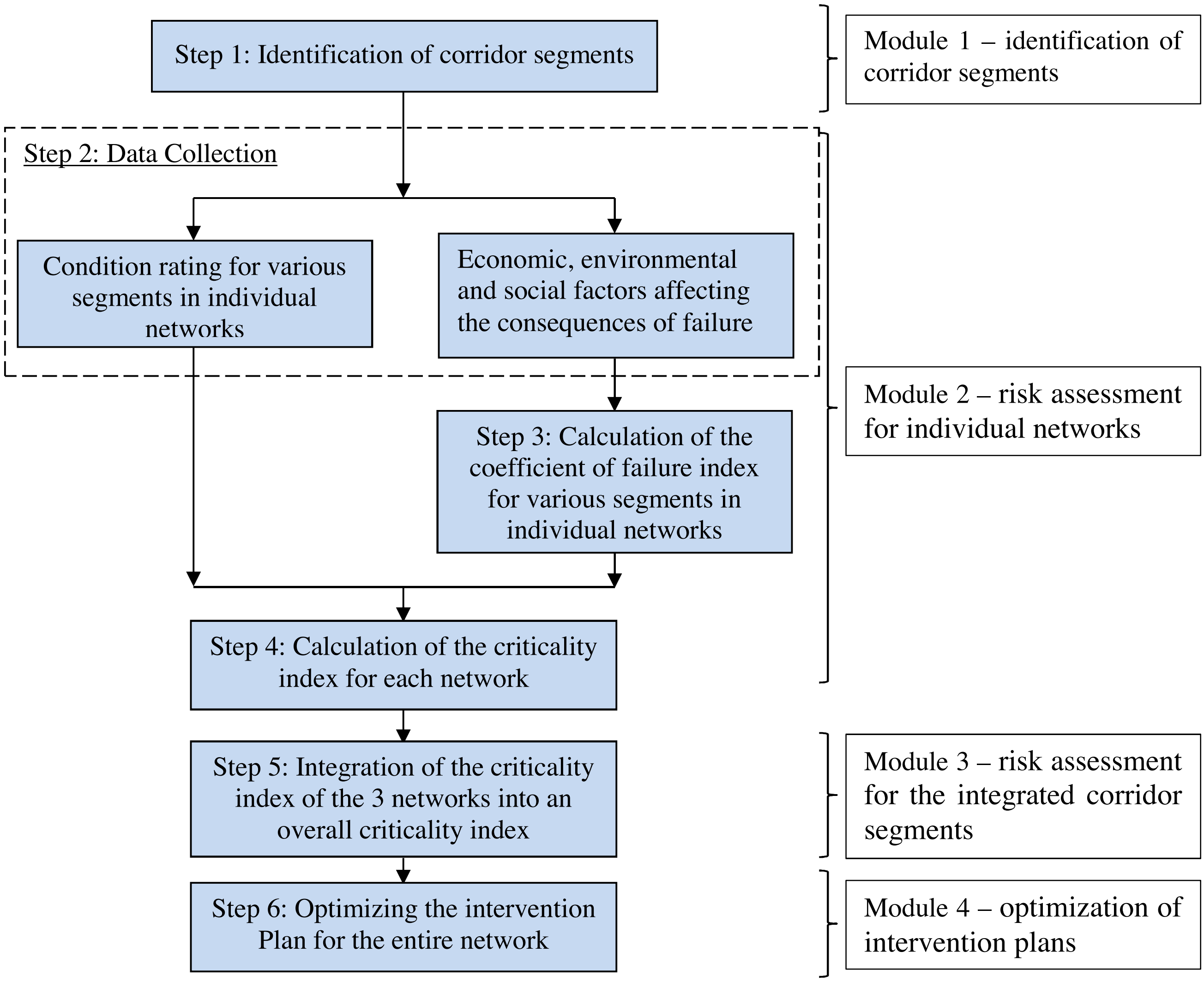


Figure 1. Proposed Model Flow Diagram

© ASCE 2014

This proposed model employs the following main steps: (1) identification of corridor segments; (2) data collection pertinent to condition rating and factors affecting the consequences of failure of the three infrastructure assets i.e. water, sewer and roads; (3) calculation of the consequence of failure index for segments in the three networks; (4) computation of the criticality index for the segments of each individual network; (5) calculation of the overall criticality index for the segments in the integrated network; (6) optimization of intervention plans for integrated networks. The four modules and their respective functions are described through the case study presented in the following section.

CASE STUDY AND DATA ANALYSIS

The case is of one of the 19 boroughs within the metropolitan area of Montreal, Canada. The area covered by this case is 24km^2. The case comprises a total length of water, sewer and roads of 70, 67 and 82km respectively (see Figure 2) to serve approximately 20,000 residents.

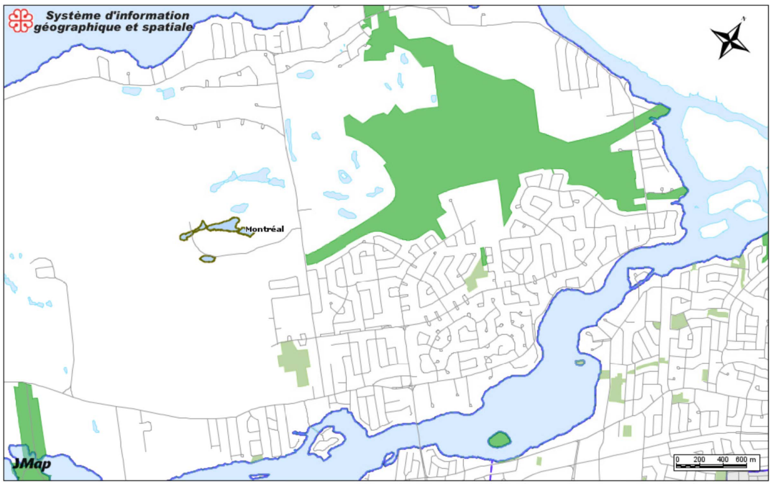


Figure 2. The Map of the Studied Area

Module 1 – Step 1 – Identification of Corridor Segments

The identification of infrastructure segments plays a fundamental role in integrated infrastructure asset management. Generally, water networks are split between isolation valves, while sewer networks are split from manhole to manhole and roads are split at intersections. These segmentation practices provide a large variability of independent length for inter-related segments. Australian National Audit Office (Better Practice Guide 2010) reported that in order to achieve effective and efficient asset management, an asset portfolio should be segmented into larger groupings that allow worthwhile analysis and decision making. In practice, the city of Montreal divides the water, sewer and road networks into segments with lengths approximately 200m. The various segmentation options were considered and discussed with the municipality managers for optimum and cost effective options. As such, it was agreed that the segment is defined as: a group of water pipes, sewer pipes, and road segment sharing the same corridor and located between the two nearest intersections (See Figure 3).

© ASCE 2014

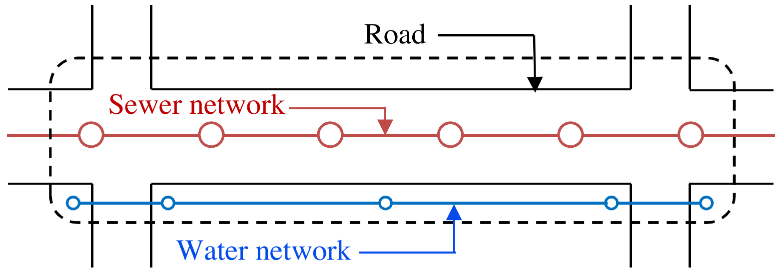


Figure 3. Segmentation of water, sewer, and road networks

Module 2 – Risk Assessment for Individual Networks

As part of the risk assessment process, the condition rating of infrastructure assets and the potential consequences of their respective failures are considered to prioritize the infrastructure inspections, rehabilitation and replacement plans. In practice, the condition assessment for the city of Montreal was evaluated, according to the Ministry of Municipal Affairs, Regions and Territory Occupancy (MAMROT) Master Plan guide for the renewal of water and sewers pipes. Based on the MAMROT, the global condition rating of the water mains (GCRW) is evaluated taking into consideration four indicators; the number of breaks over a 5 years period, the pipe material and year of installation, exposure to risk and the serviceability deficiencies. On the other hand, the global condition rating of the sewer pipes (GCRS) is evaluated using three indicators including operational deficiencies, structural condition and exposure to risk. For each network, every indicator is given a specific factor of safety which should sum up to 10. Scores are then given to individual indicators based on the evaluation of the existing condition. Once the scores are determined for all indicators, they are multiplied by their respective incremental factors. The ratings are added distinctively for both water mains and sewers to obtain the global condition rating for each asset respectively. The global condition rating scale for both water and sewer pipes ranges from 0 to 30 with 30 representing the best condition and 0 representing the worst condition. The integrated global condition rating (IGCR) for both water and sewer segments are then calculated using Equation 1.

$$\text{Integrated Global Condition Rating} = 1.6 \times \text{GCRW} + 1.4 \times \text{GCRS} \quad \text{Equation 1}$$

Once the global condition rating is calculated for integrated water and sewer segments, the current condition is established using Table 1.

Table 1. City of Montreal Integrated Water and Sewer Condition Assessment

Score	Condition Assessment
60 and less	Critical condition and require rehabilitation.
60.01 – 70	Bad condition and requires follow-ups.
70.01 – 80	Relatively good condition and failure is unlikely in the near future.
80.01 and more	Good condition and does not require further investigation at this time.

On the other hand, the city of Montreal evaluates the road condition rating based on the quality of the road surface pavement for the same water and sewer segments. They utilized a scale from 0 to 60 with 60 representing the best condition and 0 representing the worst condition. Based on the condition rating score, the current condition of the road is obtained using Table 2.

© ASCE 2014

Table 2. City of Montreal Road Condition Assessment

Score	Condition Assessment
Less than 40	Very bad condition/ unpaved
40.01 – 45	Bad condition
45.01 – 50	Poor (Passable) condition
50.01 – 55	Good condition
55.01 – 60	Excellent condition

In the proposed model, the condition ratings of water, sewer and road networks ($CR_{W,S,R}$) obtained from the condition assessment reports was used for the development of the proposed model. The condition ratings were clustered into 5 main groups and a condition rating scale ranging from 1 to 5 was used to describe the condition of the three networks in terms of criticality and rehabilitation requirements, where 1 indicates excellent condition and 5 indicates collapsed or imminent collapsed condition and requires an immediate attention and rehabilitation (see Table 3).

Table 3. Network Condition

Numeric Scale	Linguistic Scale	Description
1	Excellent	Acceptable condition.
2	Very Good	Minimal Collapse risk but potential for further deterioration.
3	Good	Collapse unlikely but further deterioration is likely
4	Poor	Collapse likely in the near future
5	Critical	Collapse imminent or collapsed

Step 2 – Data Collection

The data sets used in this case study was obtained from the City of Montreal. The data is divided into two main parts. The first part includes the condition assessment of 100 segments of water, sewer and road networks sharing the same corridor attained from the direct evaluation and inspection reports. The second part includes experts' opinion regarding the relative importance of the selected thirteen economic, environmental and social factors that affect the consequences of failure of the three networks. These data were used to develop the proposed model.

Step 3 – Calculation of the Consequence of Failure Index for Network Segments

Instead of determining consequences of failures in monetary terms, the proposed model developed a consequence-of-failure index to identify areas that will face a greater impact as a result of any potential failure. A consequence of failure index ranging from 1 to 5, with 1 indicating a very low consequence whereas 5 indicating a very high consequence, was used to transform the qualitative and quantitative risk factors into a point system based on experts' opinion. Thirteen factors affecting the cost of rehabilitation and replacement of the water, sewer and road infrastructures were identified from previous research and were considered. These factors were grouped into three main categories: economic, environmental and social factors. A survey by means of a questionnaire was conducted with the

© ASCE 2014

participation of municipal experts, consultants and contractors working in the metropolitan region of Montreal to obtain the relative weights. The respondents were asked to identify the relative importance for different factors based on their experience. The AHP was used to determine the relative importance of the selected factors (Wij). After verifying the consistency of all matrices, the relative weights (Wij) were established (see Table 4).

Table 4. Relative Weights for the Consequence of Failure Factors (Wij)

Factors	Relative Weights (Wij)		
	Water	Sewer	Road
Economic Factors	0.378		
Pipe diameter	0.080	0.080	–
Type of pipe Material	0.066	0.066	–
Average pipe depth	0.082	0.082	–
Type of soil	0.066	0.066	–
Degree of accessibility to the pipe	0.084	0.084	–
Number of road lanes	–	–	0.139
Road width	–	–	0.126
Type of road pavement	–	–	0.113
Environmental Factors	0.315		
Land use	0.100	0.100	0.093
The function of the pipe	0.100	0.100	–
Level of damage to surrounding assets	0.115	0.115	0.107
Average daily traffic	–	–	0.115
Social Factors	0.306		
Type of serviced area	0.092	0.092	0.092
Type of road	0.107	0.107	0.107
Average daily traffic	0.107	0.107	0.107

Since each consequence of failure factor has several attributes that affects its consequence of failure, the respondents were asked to assign a score (Sij) indicating the level of importance of potential failure of the three infrastructures. Experts participating in the survey were asked to allocate 1 for “insignificant impact of failure” and 5 for “Catastrophic impact of failure”. Once the relative weights and (Wij) and the potential of failure score (Sij) for the various factors were obtained for each individual network, the results were converted into a consequence of failure index by combining the relative weights (Wij) and the potential of failure score (Sij) for the various factors using Equation 2.

$$COF = \sum_{i=1}^{n} \sum_{j=1}^{m} Wij \times Sij \qquad \text{Equation 2}$$

Where,

COF = the consequence of failure index for individual network.

n, m = the number of the main factors and sub factors respectively.

Wij = the relative weigh of each sub-factor.

Sij = the score assigned for each attribute *j* within the factor *i*.

© ASCE 2014

Step 4 – Computation of Criticality Index for Network Segments

Risk matrices were used to determine the criticality index for each individual infrastructure asset ($CI_{W,S,R}$) by combining the condition rating ($CR_{W,S,R}$) and consequences of failure ($COF_{W,S,R}$) that are measured on an ordinal scale. The criticality index has a scale from 1 to 25 with 1 indicating the lowest criticality and 25 indicating the highest criticality. This scale is clustered into five risk rating levels with 1 indicating "Not Critical" and 5 indicating "Extremely Critical" (see Table 5).

Table 5. Proposed Criticality Scale

Risk Scale	Level of Risk	Required Action
1	Not Critical	Risk can be accepted and no action required.
2	Low Critical	Risk can be accepted and managed by routine procedures.
3	Moderately Critical	Risk should be scheduled for inspection to reduce the probability and/or impact of potential risks.
4	Highly Critical	Risk should be prioritized and scheduled repair/ replacement action to reduce the impact of potential risks.
5	Extremely Critical	Risk should be prioritized for immediate repair/ replacement action to eliminate risk entirely.

Module 3 – Step 5 – Risk Assessment for the Integrated Corridor Segments

Since the process of calculating the overall risk index for the combined water, sewer and road segments is simply the integration of criticality indices ($CI_{W,S,R}$) into an integrated criticality index (ICI), the average of the criticality indices for the three infrastructure networks is calculated and normalized into a scaled data ranging from 1 to 5 that represent the overall integrated criticality index. The ICI is then clustered into the same five risk rating levels as shown in Table 5.

Based on the results of the data analysis, a relation between the integrated criticality index (ICI) of the various network segments and the criticality index for the three networks (i.e. CI_W, CI_S, and CI_R) was done to predict the ICI from the criticality indices of the infrastructure assets (see Equation 3). To evaluate the accuracy of estimation, the coefficient of determination (R^2) and mean square error (MSE) were calculated. R^2 and MSE were 0.9599 and 0.0610 respectively. This indicates that the integrated criticality index for the corridor segment is successfully described by the criticality indexes of the watermain, sewers and roads.

$$ICI = -0.27 + 0.53\ CI_W + 0.54\ CI_S + 0.43\ CI_R \qquad \text{Equation 3}$$

Sensitivity Analysis and Model Verification

Two different approaches were used to test and verify the developed model. The first approach is sensitivity analysis and stability of the model to ensure that the model is performing as expected under different model parameters. The second approach is a model accuracy testing to verify the results. In the sensitivity analysis, several scenarios were assumed and applied to the model and the results were examined for any illogicality. Figure 4 shows that there is a positive relationship

© ASCE 2014

between the ICI and CI for the three criticality indices of the three networks (e.g. ICI increases as $CI_{W,S,R}$ increase).

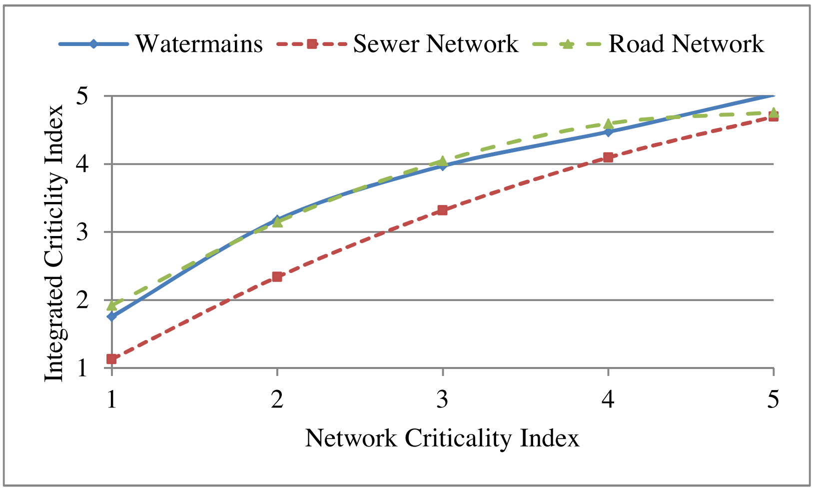


Figure 4. Integrated Criticality Index for different Criticality Indices

In order to verify the accuracy and the adequacy of the developed model, a comparison was conducted between the integrated criticality index (ICI) estimated by the developed model and the integrated global condition rating (IGCR) generated based on the city of Montreal current practices when integrating water and sewer networks. The results are shown in Figure 5 and summarized in Tables 4 and 5. Table 4 shows that according to the current practices used by the city of Montreal, the corridor segments were classified into 4 main categories based on their condition rating. However in the proposed model, the corridor segments were classified into 5 main categories based on the criticality index which is commonly used scale for risk assessment of infrastructure assets. Figure 5 shows a comparison between the integrated criticality index (ICI) and the integrated global condition rating (IGCR). Table 5 summarizes the main differences in criticality indices. It can be seen that 44% of the network segments obtained the same ICI as the IGCR and only 56% of the network segments had a 1 or 2 level differences in criticality ratings. This difference is the due to the fact that Montreal's current practices depend mainly on operational deficiencies, structural condition and exposure to risk for classifying the criticality rating but the proposed model takes into consideration both the condition assessment and the consequences of failure of the infrastructure networks to prioritize the assets.

Table 4. Criticality index for Different Segments

Condition Rating	No. of Segments	
	Proposed Model	Current Practices
1	16	0
2	39	41
3	18	15
4	20	41
5	7	3
Total	100	100

Table 5. Difference in Criticality Index

Difference	No. of Segments
0	44
1	47
2	9
Total	100

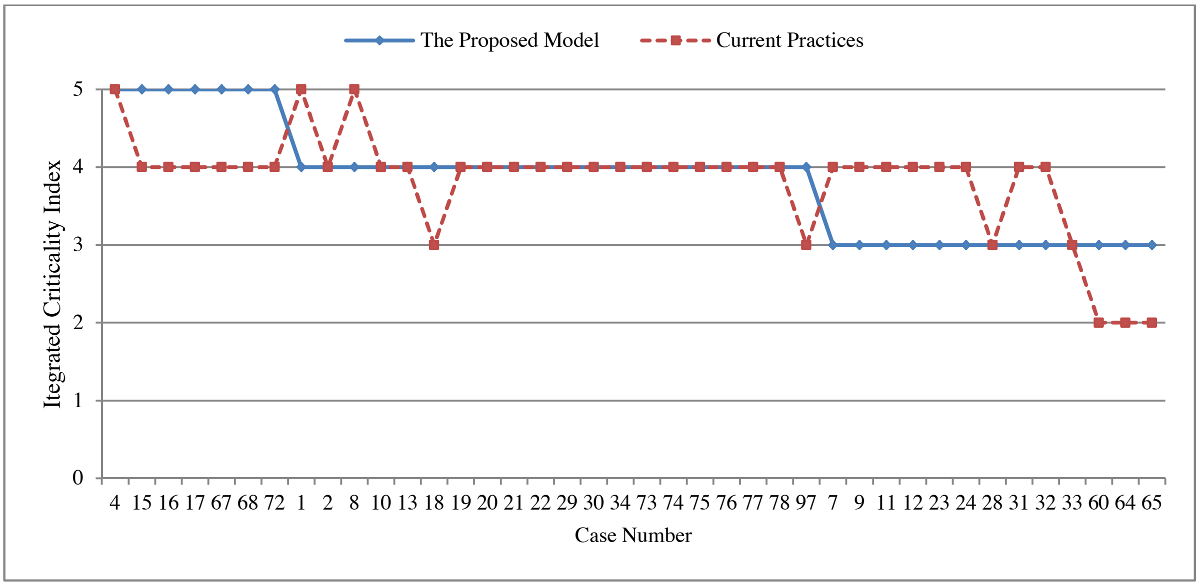


Figure 5. Comparison between Actual Practices and Model Results

SUMMARY AND CONCLUSIONS

This research presents a model designed to facilitate the decision making process for corridor rehabilitation of municipal assets. The proposed model comprises four main modules encompassing identification of corridor segments, risk assessment of individual asset networks and integrated risk assessment to identify critical corridor segments and set priorities for intervention plans. The consequences of failure for individual water, sewer and road networks were calculated using a weighted scoring system. Each network was evaluated with respect to thirteen economic, social, and environmental factors, and as a result a coefficient of failure index was calculated. A case study, from one of the 19 boroughs within the metropolitan area of the City of Montreal in Canada, was used to illustrate the developed modules and their respective functions.

The results of the analysis showed that there is a strong positive relationship between the ICI and CI for the criticality indices of the three networks. It also shows that the proposed model successfully represents the integrated criticality index for the combined water, sewer and road segments using their criticality indices as the coefficient of determination (R^2) and mean square error (MSE) were 0.9599 and 0.0610 respectively. Finally, the implementation of the proposed model using the actual data revealed that different segments were divided into five main categories based on their criticality. These categories range from “not critical” to “extremely critical”.

The developed model is expected to assist municipal engineers and decision makers in identifying critical segments of infrastructure networks in order to prioritize inspections, rehabilitation and replacement decisions and optimizing budget allocation and resource usage. The proposed model is ideal for municipalities wishing to personalize the relative weights according to their respective environmental, social and economic regional parameters. Therefore, the model emphasizes more on local experts input which adds an additional weight to the overall integrated condition

© ASCE 2014

assessment of the networks. This will result in greater consistency for the municipality taking into consideration their respective needs and prioritization schemes. As a result, the model is provided to further refine existing condition ratings in such a way that existing municipal practices are taken into considerations or to provide for the integrated assessment of existing assets within a municipality if none is existing.

REFERENCES

Al Barqawi, H., & Zayed, T. (2008). "Infrastructure management: Integrated AHP/ANN model to evaluate municipal water mains' performance." *Journal of Infrastructure Systems*, Vol. 14, No. 4, p. 305–318.

American Society of Civil Engineering (ASCE). (2013). "2013 ASCE's Report Card for America's Infrastructure", http://www.infrastructurereportcard.org/a/#p/home .

Australian National Audit Office, (2010). "Better practice guide on the strategic and operational management of assets by public sector entities." *Better Practice Guide*, Australia.

Bandara1 N. and Gunaratne M. (2001). "Current and future pavement maintenance prioritization based on rapid visual condition evaluation", *Journal of Transportation Engineering*, ASCE, 127(2), 116–123.

Baur, R., and Herz, R. (2002). "Selective inspection planning with aging forecast for sewer types." *Water science and technology*, 46(6–7), 389–396.

Chen, P., Scown, C., Matthews, H. S., Garrett, J. H., and Hendrickson, C. (2009). "Managing critical infrastructure interdependence through economic input-output methods." *Journal of Infrastructure Systems*, 15(3), p. 200–210.

Christodoulou, S., Aslani, P., and Vanrenterghem, A. (2003). "Risk analysis framework for evaluating structural degradation of water mains in urban settings using neurofuzzy systems and statistical modeling techniques". World Water and Environmental Resources Congress, ASCE, Philadelphia, PA, USA, 1–9.

Dudenhoeffer, D., Permann, M., and Manic, M. (2006). "CIMS: A framework for infrastructure interdependency modeling and analysis", Proceedings of the 2006 Winter Simulation Conference, INL/CON-06-11975, 478–485.

Dueñas-Osorio, L., Craig, J., Goodno, B., and Bostrom, A. (2007), "Interdependent response of networked systems", *Journal of Infrastructure Systems*, 13(3), 185–194.

Fares, H., and Zayed, T. (2009). Risk assessment for water mains using fuzzy approach. Building a Sustainable Future – *Proceedings of the 2009 Construction Research Congress*, Seattle, WA, USA, 1125–1134.

Gomes, L. F. A. M. (1990). "Modeling interdependences among urban transportation system alternatives within a multicriteria ranking framework." *Journal of Advanced Transportation*, 24(1), 77–85.

Halfawy, M. (2008). "Integration of municipal infrastructure asset management processes: challenges and solutions", *Journal of Computing in Civil Engineering*, 22(3), 216–229.

Iniestra, J. G., and Gutierrez, J. G. (2009). "Multi criteria decisions on interdependent infrastructure transportation projects using an evolutionary-based framework." *Applied Soft Computing*, 9(2), 512–526.

© ASCE 2014

Islam, T., and Moselhi O. (2011). "Integrated asset management of roads, water mains and sewers." CSCE 2011, *Annual Conference of the Canadian Society for Civil Engineering*, Ottawa, Ontario, p. GC1 – GC-069-2.

Islam, T., and Moselhi, O. (2011). "Geospatial interdependence for integrated municipal infrastructure", *ASCE, Journal of Infrastructure Systems*, 18(2), 68–74.

Kleiner, Y., Rajani, B., & Sadiq, R. (2006). "Failure risk management of buried infrastructure using fuzzy-based techniques." *Journal of Water Supply Research and Technology*: Aqua, 55(2), 81–94.

Rajani, B., Kleiner, Y., & Sadiq, R. (2006). "Translation of pipe inspection results into condition ratings using the fuzzy synthetic evaluation technique." *Journal of Water Supply Research and Technology*: Aqua, 55(1), 11–24.

Rinaldi, S., Peerenboom J., and Kelly T., (2001) "Identifying, understanding, and analyzing critical infrastructure interdependencies," *IEEE Control Systems Magazine*, IEEE, December 2001, 11–25.

Rogers, P. and Grigg, N. (2006). "Failure assessment model to prioritize pipe replacement in water utility asset management". *ASCE 8th Annual Water Distribution Systems Analysis Symposium*, Cincinnati, Ohio, USA, 1–17.

Ruwanpura, J., Ariaratnam, S. T., and El-Assaly, A. (2004). "Prediction models for sewer infrastructure utilizing rule-based simulation." *Civil Engineering and Environmental Systems*, 21(3), 169–185.

Sadiq, R., Rajani, B., & Kleiner, Y. (2004). "Probabilistic risk analysis of corrosion associated failures in cast iron water mains." *Journal of Reliability Engineering and System Safety*, 86(1), 1–10.

Salman, B., and Salem, O. (2012). "Risk assessment of wastewater collection lines using failure models and criticality ratings", *Journal of Pipeline Systems Engineering and Practice*, 3(3), 68–76.

Shahata, K. and Zayed, T (2009). "Integrated management approach for infrastructure assets." *Proceeding, INFRA Conference*. Mont-Tremblant, Québec, Canada, 1–10.

Teng, J., Tzeng, G. (1996). "A multiobjective programming approach for selecting non-interdependent transportation investment alternatives." Transportation Research–B, 30(4), p. 291–307.

Yan, J., & Vairavamoorthy, K. (2003). "Fuzzy approach for pipeline condition assessment." *New Pipeline Technologies, Security and Safety*, ASCE, Baltimore, MD, USA, 467–476.

© ASCE 2014

Flexural Retrofitting of Reinforced Concrete Structures Using Green Natural Fiber Reinforced Polymer Plates

Ignacio Cervantes[1], Lisa AungYong[2], Kyle Chan[3], Yu-Fu Ko[4], and Sergio Mendez[5]

[1]Ignacio Cervantes, Presenting author, Graduate Student Researcher, Civil Engineering and Construction Engineering Management, California State University, Long Beach, Long Beach, CA; E-mail: nachitito_1@yahoo.com
[2]Lisa AungYong, Graduate Student Researcher, Chemical Engineering, California State University, Long Beach, Long Beach, CA; E-mail: tatuhm1@aol.com
[3]Kyle Chan, Graduate Student Researcher, Civil Engineering and Construction Engineering Management, California State University, Long Beach, Long Beach, CA; E-mail: kyleechan@gmail.com
[4]Yu-Fu Ko, Ph.D., P.E., Corresponding author, Assistant Professor, Civil Engineering and Construction Engineering Management, California State University, Long Beach, Long Beach, CA; E-mail: Yu-Fu.Ko@csulb.edu; Tel: (562)985-7884
[5]Sergio Mendez, Ph.D., Assistant Professor, Chemical Engineering, California State University, Long Beach, Long Beach, CA; E-mail: smendez.csulb@gmail.com; Tel: (562)985-7532

ABSTRACT

Experimental and numerical studies were carried out to determine the suitability of Green Natural Fiber Reinforced Polymer (GNFRP) composite plates, fabricated with a bio-derived resin matrix and embedded natural hemp fibers acting as tensile and transverse reinforcement and produced using a vacuum resin infusion process, to be used for strengthening reinforced concrete (RC) beams for flexural loading. The experimental study consisted of four RC beams: three of them used for control purposes (one plain, two with the traditional glued Carbon Fiber Reinforced Polymer (CFRP) composites plates) and one with 10 glued layers of the GNFRP composite plate to study the proposed strengthening system. Strength, ductility and failure modes were analyzed and compared to the numerically obtained results by ABAQUS, the finite element software. The increased stiffness and the ultimate strengths of RC beams strengthened with Green Natural Fiber Reinforced Polymer (GNFRP) composites plates confirmed that strengthening RC beams using externally bonded GNFRP composites plates fabricated with a bio-derived resin matrix and natural hemp fibers is a feasible alternative and a practical approach to retrofitting reinforced concrete structures.

INTRODUCTION

© ASCE 2014

A country's infrastructure such as bridges, buildings, dams, and other types of structures lose some of its strength due to its normal use and also deteriorate as they age. To remedy this situation, a retrofit system is an alternative. Systems commonly used for retrofitting applications include external bracings with steel sections, adding additional concrete to defective concrete members, bonding or bolting steel plates to the damaged areas of the structure, or utilizing Fiber Reinforced Polymer (FRP) plates for strengthening. Many factors must be considered based on the type of strengthening technique envisioned, the weight of the plates, anchoring and installation issues, road closures, heavy equipment, long installation periods and the added dead weight to the structure, which could potentially modify its seismic response. An alternative which is not very expensive is to retrofit the structure with the addition of FRP plates, which is a fairly recent strengthening system (Hollaway and Leeming, 1999). These materials are ideal for retrofit applications due to their versatility and ease of installation, no heavy equipment, scaffolding and specialized skill is needed, the plates are rapidly applied, and this system is often times less expensive than other techniques. The purpose of retrofitting structures with green materials (bio-composites) is to attempt to diminish the environmental impact caused by the production and disposal of man-made, synthetic fibers. For this purpose, it was necessary to use as many biodegradable components as possible for the manufacture of the green composite. Therefore, a resin which utilized bio-derived materials was chosen for the infusion process as the matrix adhesive with embedded hemp fibers for the manufacture of the GNFRP composites plates.

RESEARCH SIGNIFICANCE

The significance of the proposed study includes: (a) determination of two very important elements in any construction or retrofit proposal made by architects, construction managers or civil engineers: the first is attaining the desired strength level without compromising safety, appearance, dimensional constraints and durability. The second is determining if the proposed strengthening technique will be at least as expensive, or ideally cheaper, than the current Carbon Plate bonding technique; (b) utilizing a "green" composite material, which was originally developed, fabricated, and tested in the Department of CECEM and Chemical Engineering at the California State University Long Beach; and (c) how the newly developed "green" composite material could potentially serve as an alternative to the carbon-fiber based materials currently used by the retrofitting industry. Previous researchers, such as Icchapora et al. (2008), Placet et al (2004)., and Sawpan et al (2011), studied whether bio composites such as GNFRP (Green Natural Hemp Fiber Plate composites) could replace glass fiber reinforced unsaturated polyester resins for structural applications; they indicated that utilizing unidirectional fiber reinforcements appeared to be a promising solution for the manufacture of composites where high mechanical performance is needed, and point out that in certain composite applications, natural fibers demonstrate competitive performance similar to that of glass fibers. With respect to the eco resin utilized for infusion, some of its advantages are as follows: (1) Improved adhesion and elasticity, (2) Improved mechanical performance, (3) Reduces environmental impact: 50% minimum reduction in CO and greenhouse gas emissions, (5) the Green chemistry eliminates harmful by-products, (6) Reduced power and water consumption for the environment and user, among other. For the hemp composite plate lamination, the Vacuum Infusion Process (VIP) was utilized for the present study; this is a technique that uses vacuum pressure to drive resin into a laminate; materials are laid dry into the mold and the vacuum is applied before resin is introduced. Once a complete vacuum is achieved, resin is sucked into the laminate via tubing. Vacuum bagging greatly improves the fiber-to-resin ratio, and results in a stronger and lighter product.

EXPERIMENTAL PROGRAM

The Green Natural Fiber Reinforced Polymer (GNFRP) composite plates to be used for the proposed strengthening system were locally manufactured. Experimental tensile tests on sample strips were performed to obtain the mechanical properties of the GNFRP composites plates. In addition, Finite Element Analysis (FEA) models were developed to simulate crack patterns, failure modes, and ultimate capacities. Parametric studies were also performed.

CHALLENGES

The fabrication of hemp fiber plates was deemed to be a challenge and the application was considered to be a new reinforcing technique. As such, it required extensive testing.

ECONOMICS PERSPECTIVE

The economists M. Kahn and D. M. Levinson (Kahn and Levinson, 2011) proposed an approach which favors the retrofitting of the overall existing infrastructure instead of rebuilding it. He noted that the current system of government creates a bias toward funding new construction rather than upgrading existing infrastructure, since new construction is less likely to generate support for the politicians controlling the budgets, and he concludes that the upgrade approach is more viable to extend the useful life of a structure while minimizing capital outlay.

EXPECTED RESULTS

A number of distinct failure modes of RC beams bonded with FRP composite plates have been observed in numerous experimental studies by Teng et al. (2002). The preferred modes of failure to be designed for are (i) concrete crushing following yielding of steel tension reinforcement and (ii) FRP rupture following yielding of steel reinforcement, (when strengthening reinforced concrete structures). In both modes, yielding of the steel tension reinforcement precedes failure by either concrete crushing or rupture of the FRP, which ensures that there is a warning of failure, despite the fact that these modes generally show limited ductility. An undesirable

© ASCE 2014

failure mode is failure by concrete crushing or FRP rupture (particularly when the rupture strain is small as is the case for high-modulus CFRP), without yielding of steel reinforcement (Hollaway and Teng, 2008).

GENERAL FRP DESIGN SPECIFICATIONS

The ACI 440.2R-02 (2002) design guideline gives design recommendations based on limit-state principles, the committee points out that FRP strengthening systems should be designed in accordance with ACI 318-99 strength and serviceability requirements, using the load factors, and the strength reduction factors required by that publication; strengthening limits must be reasonable and must be imposed to guard against collapse of the structure in case that bond or other failure of the FRP system occurs due to fire, vandalism, or other causes.

Flexural strengthening: ACI 440.2R-02 committee. Chapter 9 of the ACI 440.2R-02 (2002) design guideline presents guidance on the calculation of the flexural strengthening effect of adding longitudinal FRP reinforcement to the tension face of a reinforced concrete member. The following assumptions, in condensed form, are made in calculating the flexural resistance: (1) Design calculations are based on the actual dimensions, internal reinforcing steel arrangement, and material properties of the existing member being strengthened; (2) A plane section before loading remains plane after loading; (3) There is no relative slip between external FRP reinforcement and the concrete; (4) The shear deformation within the adhesive layer is neglected; (5) The maximum usable compressive strain in the concrete is 0. 003; (6) the tensile strength of concrete is neglected; and (7) The FRP reinforcement has a linear elastic stress-strain relationship to failure. The maximum strain level that can be achieved in the FRP reinforcement will be governed by either the strain level developed in the FRP at the point at which: (a) Concrete crushes, (b) FRP ruptures, or (c) FRP debonds from the substrate. The calculation of the ultimate strength of an FRP strengthened beam should satisfy strain compatibility and force equilibrium conditions and should consider the governing mode of failure. Several calculation procedures can be derived to satisfy these conditions. The nominal flexural strength of the section with FRP external reinforcement can be computed following Eq. (9-11) found in the ACI 440.2R-02 (2002) design guideline. An additional reduction factor Ψ_f is applied to the flexural strength contribution of the FRP reinforcement. A factor $\Psi_f = 0.85$ is recommended by the ACI 440.2R-02 (2002) design guideline. The nominal flexural strength is:

$$M_n = A_s f_s \left(d - \frac{\beta_1 c}{2}\right) + \Psi_f A_f f_{fe} \left(h - \frac{\beta_1 c}{2}\right)$$

Where f_{fe} is stress level in FRP reinforcement (MPa); c is distance from extreme compression fiber to the neutral axis, (mm); h is thickness of member (mm); β_1 is taken as the value associated with the Whitney stress block; A_f is area of FRP external reinforcement, (mm^2); As is area of non-prestressed steel reinforcement, (mm^2); d is distance from extreme compression fiber to the neutral axis, (mm); fs is stress in non-prestressed steel reinforcement, (MPa).

Natural fiber reinforced polymers. Natural, biodegradable fibers have been used as fillers for composites in the automotive industry, and for exterior and interior panels, but limited literature exists on their use as construction strengthening materials. (Karus and Vogt, 2004). Two main reasons for the interest in biodegradable materials are: (1) the growing problem of waste, which results in the general shortage of landfill availability, and (2) the need for environmentally responsible use of resources. Sawpan et al. (2011) determined that of the several natural fibers available for reinforcing composites, cellulose was deemed to be of particular interest, since it has very high theoretical strength (15 GPa) and obtainable strength (8 GPa). However, the strength of a single hemp fiber is only 800-2000 MPa (Madsen et al., 2004). Madsen et al. (2004) stated that this is still a high strength compared to 500-700 MPa, which is typical fiber strength obtained with plant fiber reinforced composites today.

EXPERIMENTAL WORK

The program considered items such as loading characteristics, failure mechanisms for FRP strengthened beams, geometric and loading parameters, and in particular, the effects which may initiate overall collapse. The design of the GNFRP plate was performed by the Department of Chemical Engineering at the California State University, long Beach, and the actual production of the Hemp fiber reinforced polymer plates (GNFRP), took place at the facilities of the Department of Mechanical and Aerospace Engineering Lab by means of a production method called Vacuum Infusion Process. The CFRP reference plates were obtained from a local manufacturer, ACP Composites® Inc. Table 1 shows typical properties of natural and synthetic fibers (Ichhaporia, 2008), The properties for the CFRP are as determined by the manufacturer, ACP Composites® Inc. and the properties for the GNFRP plates were obtained from the existing literature and complemented by testing and are shown on Table 2.

TABLE 1. Properties of Natural and Synthetic Fibers.

Type of Fiber	Density g/cm3	Tensile Strenght (Mpa)	Young's Modulus (Gpa)	Elongation at Break (%)
Cotton	1.5-1.6	287-800	5.5-12.6	7.0-8.0
Jute	1.3-1.45	393-773	13-26.5	1.16-1.5
Flax	1.5	345-1100	27.6	2.7-3.2
Hemp	-	690	-	1.6
Ramie	1.5	400-938	61.4-128	1.2-3.8
Sisal	1.45	468-640	9.4-22.0	3-7
Pinneaple	-	413-1627	34.5-82.51	1.6
Coir	1.15	131-175	41370	15-40
E-glass	2.5	2000-3500	70	2.5
S-Glass	2.5	4570	86	2.8
Aramid	1.4	3000-3150	63-67	3.3-3.7
Carbon	1.7	4000	230-240	1.4-1.8

Reinforced beams. Four identical reinforced concrete beam specimens were manufactured in the Structures Laboratory of the Department of CECEM at California State University, Long Beach. The beams were designed as under reinforced, tension controlled, with a 152.4 mm by 152.4 mm square cross section, they were 2438.4 mm in length, and had a 31.75 mm concrete cover with an average compressive strength, $f_c' = 37.92$ MPa (5,500 psi). Longitudinal tension reinforcement was provided in the form of two #4 deformed bars, grade 40 ($f_y = 275.79$ MPa), the transverse reinforcement was made out of #3 plain bars. All the beams tests in the program were carried out under four point bending. The shear span for all beams was 7.36. The setup of the configuration, support conditions and loading arrangement is shown in Figure 1.

TABLE 2. Mechanical Properties of FRP Plates.

	CFRP[1]	GNFRP[2]
Plate Dimensions (mm) (width x thickness)	152.4 x 0.762	152.4 x 6.35
Ultimate Tensile Strenght, (GPa)	1.965	1.17
Tensile Modulus, (GPa)	120.66	72.39
Compressive Strenght, (GPa)	1.1	0.66
Compressive Modulus, (GPa)	117.215	70.329
Flexural Strenght, (GPa)	2.14	1.284
Flexural Modulus, (GPa)	117.215	70.329
Rupture Strain, (mm/mm)	0.017	0.0102

[1]As per Manufacturer.
[2] Determined from Testing and FEM.

The instrumentation for the beams is summarized as follows: (1) Load: this was measured using a digital pressure gauge which was attached directly to the hydraulic system, (2) Deflections: these were measured at midspan using a digital height gauge, and (3) Concrete strains: these were measured using general purpose analog strain gauges connected to a scanner which monitored strains in the tension and compression zones of the concrete and of fibers placed at the end, quarter, and midspan on the external surface of the FRP plates. All output was recorded and channeled to computers to provide continuous monitoring through the entire load cycle.

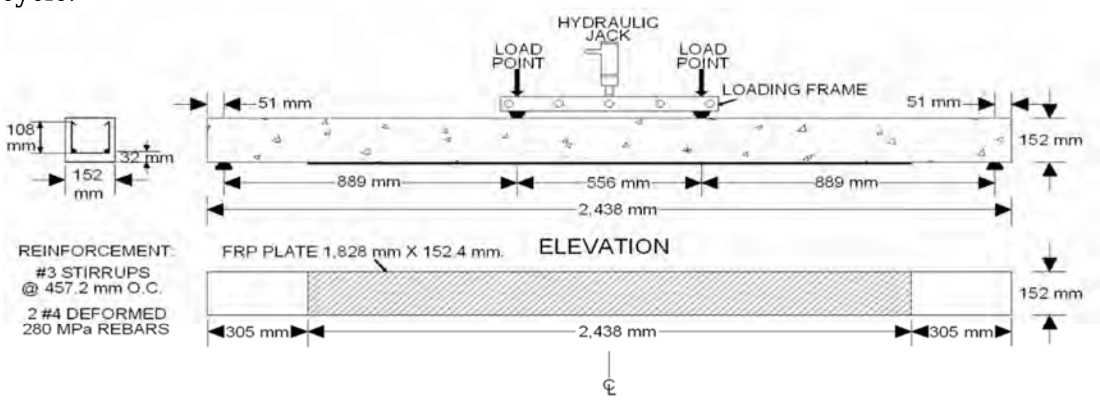


Figure 1. Arrangement for destructive testing of beams.

Description of the RC beams. The first beam was unstrenghtened and labeled Control Beam. The second control beam, labeled 1-layer CFRP Beam, was strenghtened with one unidirectional strip of Carbon fiber reinforced polymer which completely covered the width of the soffit, and it stopped 254 mm short of each end of the beam (See Fig. 1). The third beam in this study was labeled 2-layer CFRP Beam, this beam was retrofitted with two plys of CFRP to study the influence of excess strenghtening on the system, and the last beam was labeled 10-layer GNFRP

Beam, and had a composite layup plate which consisted of 5 double layers of the GNFRP material (total of 10 layers), with bi-directional, mutually orthogonal fibers on each lamina, stacked with a fiber orientation (per lamina) of 0,90 degrees and -45,+45 degrees. To complement the actual experimental testing, a computer model was implemented to attempt model the physical system as close to reality as possible using the commercially available code Simulia ABAQUS [7]. The Hashin criteria damage for composites module included in ABAQUS (2011) was applied to the FRP's.

Results. The strengthening system increased the rigidity of the beams, which was dependent upon the amount external reinforcement. A 120 percent capacity increase was recorded for the 1-layer CFRP beam, and a 68 percent increase was recorded for the GNFRP beam, as compared to the unstrengthened, plain control beam. A significant observation was that ductility decreased for both the FRP beams but it was more severe for the CFRP beam as compared to the unstrengthened beam, the increase in rigidity came at a sacrifice of ductility.

Failure modes. The debonding failure for the CFRP beam (critical diagonal crack debonding failure), occurred because the plate end was located in a zone of high shear force and low moment. Before failing, however, the plate showed important contributions to the overall mechanical performance of the section: (a) it restrained crack opening, which allowed the concrete to develop better interlocking and dowel action between the aggregates, creating a tension stiffening effect, (b) it controlled crack widths in the tension zone, which is usually controlled by the internal reinforcement for unstrengthened beams. The beam which had 2 layers of CFRP showed increased stiffness, however, the ultimate load the beam was able to sustain before it failed catastrophically was significantly lower (54.49 kN) than the one sustained by the single layer CFRP beam (58.69 kN). In this respect, it was determined that excess reinforcement, contrary to common sense, decreases the load-carrying capacity of strengthened members, increases the brittleness of the section and increases both material and labor costs. Therefore, the 2-layer CFRP strengthened beam was excluded for the remainder of the study and only the 1-layer strengthened CFRP beam was considered for the purposes of comparing it with the GNFRP reinforced beam. As with the observed horizontal rupture failure of GNFRP tension coupon specimens, the plate utilized for the strengthening system ruptured under the applied load zone, below the constant moment region. The failure of the CFRP-plated beams was due to flexural failure of the critical section, and it is shown in Figure 2. The GNFRP plate rupture failure is shown in Figure 3.

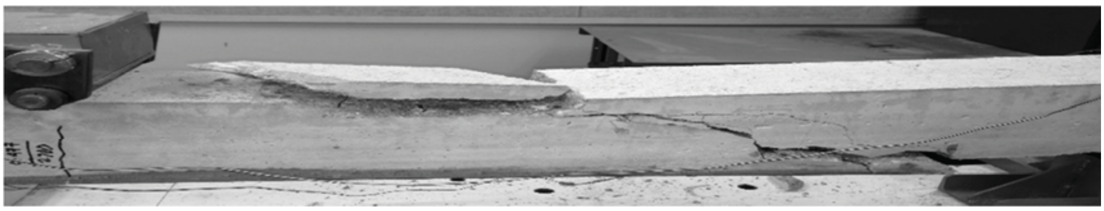


Figure 2. Main shear-flexure crack and RC cover failure for CFRP beams.

© ASCE 2014

Figure 3. Observed experimental plate rupture failure of GNFRP reinforced beam.

Load-deflection responses. The load-deflection response of the 1-layer CFRP, 10-layer GNFRP strengthened, and the plain RC beams are shown in Figure 4. The comparison revealed promising findings for considering hemp fibers as reinforcement media for fabricating FRP plates which could be utilized as structural strengthening materials. An added benefit of the plating was that it lowered the neutral axis (N.A.) position of the strengthened section. This reduced the strains in the concrete section and as a result, more of the concrete was in compression, resulting in a more efficient use of the material. It also helped to reduce the height of the cracks in the tension zone, which were observed to remain constant as the test progressed. The position of the N.A. obtained analytically following code ACI 318-08 (2008), for the unreinforced beam was 19.30 mm, while the N.A. position for the single layer CFRP beam following guideline ACI 440.2R-02 (2002), was 43.94 mm.

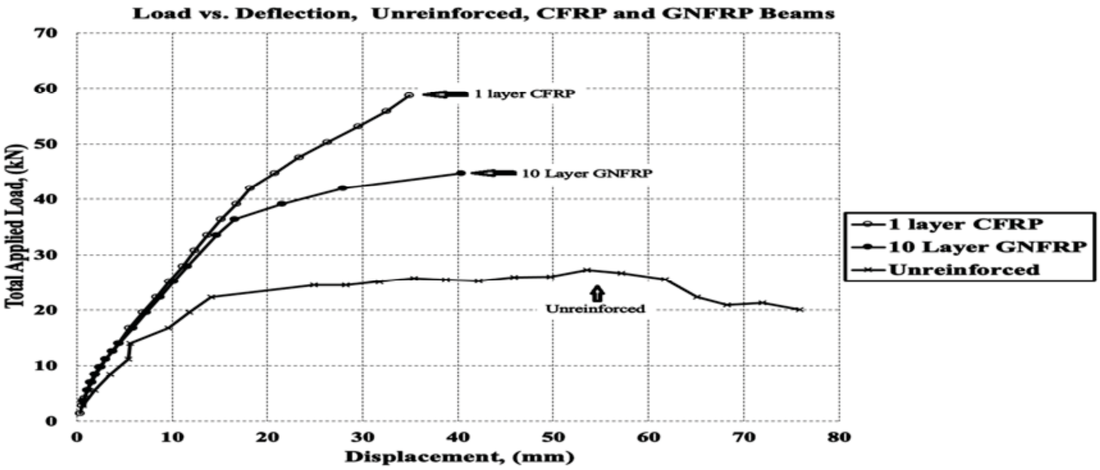


Figure 4. Comparisons of experimental load-deflection responses for 1-layer CFRP, 10-layer GNFRP strengthened, and Unreinforced RC beams.

At the early loading stages the strains had similar distributions, since concrete dominated the strain behavior at low load levels. However, as the displacement increased past 27.94 mm, the strains in the concrete at the gauge location exceeded the usable strain of concrete. For the CFRP plated beam and at the same displacement, the recorded strain value was about 6000 microstrains, or 0.6 percent, which was under the ultimate strain at rupture, given by the manufacturer as 1.4 percent. For the GNFRP, the maximum strain at the same displacement was about 10000 microstrains, or 1 percent, which shows higher elongation than that shown by the CFRP plate. The ultimate rupture strain at the ultimate limit state for the GNFRP

© ASCE 2014

plate was recorded as 14000 microstrains, or 1.4 percent, showing that the plate allowed for larger deflections than the CFRP plate before it failed.

Comparison of strength and deflection responses for all beams. Results from the study showed that FRP strengthened beams were linked to lower maximum deflections and lower strains throughout the sections. The main objective was to determine if the GNFRP beam could perform better than the plain RC beam, and how close the GNFRP beam would come to the capacity obtained from the CFRP beam. The results showed that there was an increase of 120 percent in the load carrying capacity for the CFRP beam as compared to the unstrengthened beam (from 26.66 kN to 58.69 kN), but the ductility decreased by 117 percent (decreased from 75.89 mm to 34.93 mm). This increase in stiffness explains the brittle nature of FRP strengthened beams. With respect to the GNFRP beam, an increase of 68 percent in load carrying capacity was recorded as compared to the unreinforced beam (from 26.66 kN to 44.72 kN), and the ductility decreased by only 88 percent (from 50.8 mm to 40.4 mm), compared to the CFRP ductility decrease of 117 percent. With respect to the CFRP beam, a decrease of 31 percent in strength was recorded (from 58.69 kN to 44.72 kN), but the ductility increased by 15.56 percent (from 34.93 mm to 40.4 mm), compared to the CFRP strengthened beam. The results are summarized on Table 3; Table 4 presents the experimental results of the measured forces and strains for the three beams in the study, and they are compared to the output obtained from ABAQUS Ver. 6.10.1 (2011).

Table 3. Percent Increase/Decrease in Capacity/Deflection of Beams.

Comparison	Change			
	Strenght (Percent)	Applied Load (kN)	Deflection (Percent)	Measured Displacement (mm)
CFRP To Plain Beam	+120	38.66	-117	-40.97
GNFRP To Plain Beam	+68	24.69	-88	-35.33
GNFRP To CFRP Beam	-123	-13.97	15.56	5.44

Finite element analysis (FEA) of CFRP and GNFRP strengthened, and plain RC beams. The following parameters were chosen from both the FE model and the experimental results: (a) the load-displacement responses for the beams, (b) the strain development in concrete and in the FRP plates, and (c) crack patterns at failure. The FE analysis results seemed to agree relatively well with the experimental results. the finite element analysis closely modelled the response of the unreinforced concrete beam, although for the FRP reinforced beams, it slightly over-predicted both the stiffness and the ultimate load values obtained from the experiments for the GNFRP, and under-predicted those values for the CFRP beams. On the other hand, the ultimate deflection was under-predicted for the unreinforced beam. Regarding the comparison of experimental and FEA strains, the model diverges from the experimental results around where plastic deformation begins, so the model may not be accurately modeling the plastic properties of the material, although the elastic region seems to model pretty close the experimental results. The same FEA model for the unreinforced beam served as base model for the FRP strengthened beams. The model helped to confirm the theoretical calculations based on design codes.

© ASCE 2014

Table 4. Comparison of Experimental and Numerical Force and Strain Values for Selected Displacements.

	Forces, CFRP Beam		Forces, Unreinforced		Forces, GNFRP Beam		Comp. Strains Unreinforced		Strain, GNFRP Plate Center		Strain, CFRP Plate Center	
Displ.	Exp.	FE	Exp.	FE	Exp.	FE	Exp.	FE	Exp.	FE	Exp.	FE
(mm)	(kN)		(kN)		(kN)		(mm/mm)		(mm/mm)		(mm/mm)	
0.33	1.40	2.08	2.79	3.01	3.34	2.00	-0	-2.5E-05	-	-	31	35
2.54	9.79	11.61	6.68	7.97	11.13	10.68	-0	-0.0004	3E-04	0.000361	208	289
6.95	19.57	22.56	15.13	15.35	19.36	19.14	-0	-0.00021	0.001	0.000906	1212	720
18.21	41.94	44.10	23.14	23.10	37.83	36.05	-0	-0.00053	0.004	0.00221	3314	1861
20.8	44.74	46.73	24.03	23.32	38.72	38.45	-0	-0.00053	0.005	0.00259	4692	2109
23.31	47.53	49.84	24.25	23.45	40.05	40.27	-0	-0.00051	0.009	0.00281		
26.21	50.33	5.25	24.48	23.76	41.94	42.90	-0	-0.00049	0.01	0.00311		
29.54	53.12	54.74	24.52	23.99	-	-	-0	-0.00047	0.011	0.005		
45.47	55.92	56.07	25.15	24.12	-	-	-	-	-	-		
34.93	58.72	55.63	25.78	24.16	-	-	-	-	-	-		
38.1			25.53	24.25	44.28	48.06	-	-	0.13	0.00479		

Force and strain distribution comparison. The strain and force values were compared at selected matching displacements and the results showed that the force values obtained from ABAQUS represent with reasonable accuracy the values recoded experimentally. A possible explanation in the ABAQUS strain output differences is that this could have been caused by the fact that the transverse FRP material properties defined in the FE model were approximated by proportion, therefore, they could have had a large effect on the strain results. For the most part, the strain data were in good agreement with the numerical and experimental results, as shown in Figure 5.

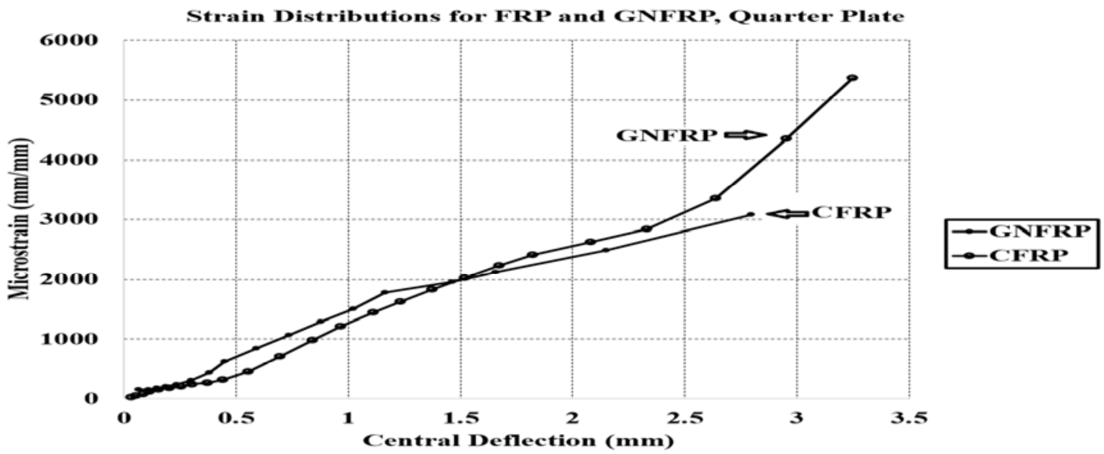


Figure 5. Experimental and FEA strain distributions as a function of displacement at quarter of GNFRP plate.

Crack Pattern Simulation Results. Crack patterns were selected at two points in the analysis for the 1- layer CFRP strengthened beam, the 10-layer GNFRP strengthened beam, and plain RC beam. As shown on Figure 6, beginning at the load level which caused initial cracking, which was about 13.34 kN. The crack patterns observed experimentally (CAD drawn) are also shown and are compared to the ABAQUS output that most closely approximates cracking in concrete, namely, PEEQT (the equivalent plastic strain for concrete in tension), which indicates if the material is currently yielding or not. For clarity, only the cracks in which the plastic strain is large enough are shown. In Figure 6, the lighter areas in the model represent the damage (high effective plastic strain) in the specified material module for concrete. A final observation is that in real-life experiments, shear stresses can still be transmitted across the cracks while in numerical analysis, as soon as the concrete cracks, the loads will be transmitted to the reinforcing bars. Figure 7 presents graphically the load-deflection responses for the 1-layer CFRP, the 10-layer GNFRP strengthened, and plain RC beams in the study. Figure 7 shows that the FEA model was deemed to reasonably predict forces, strains and displacements for all the beams.

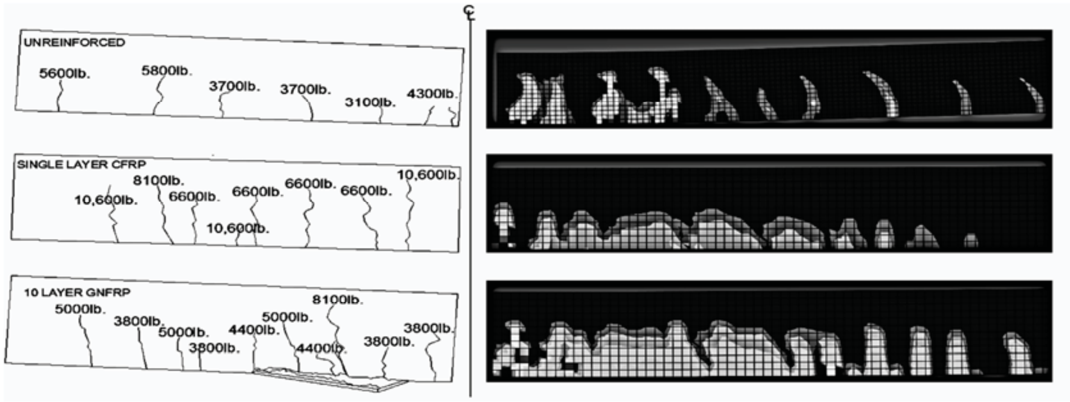


Figure 6. Approximate crack patterns for the plain RC beam, CFRP strengthened RC beam, and GNFRP strengthened RC beam obtained from experimental observations (left: top to bottom) compared to ABAQUS FEA (right: top to bottom).

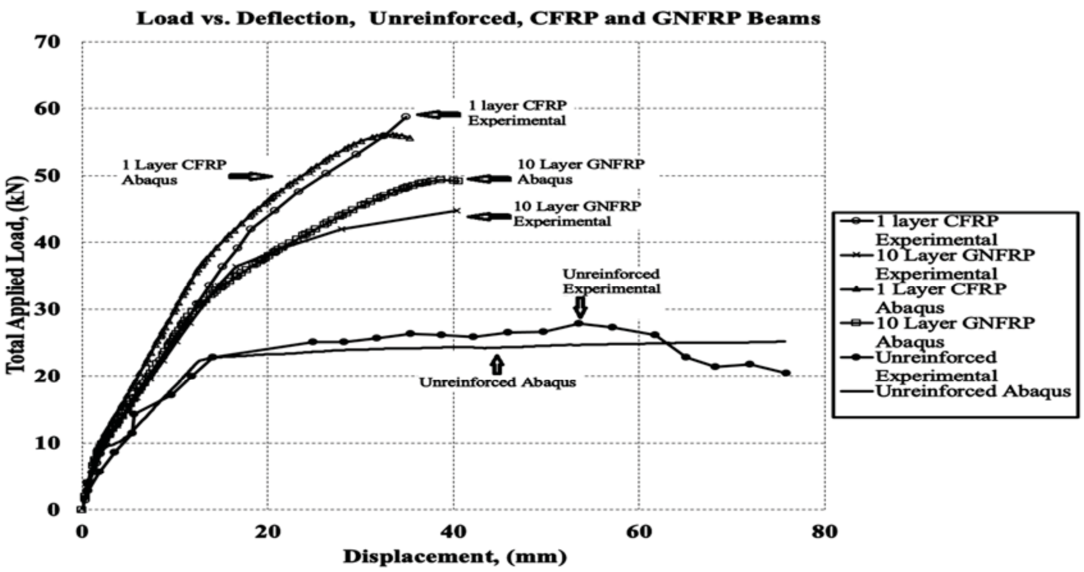


Figure 7. Summary of ABAQUS FEA and experimental results for 1-layer CFRP, 10-layer GNFRP strengthened, and plain RC beams.

CONCLUSION

In this Research, experimental studies were carried out to determine the suitability of Green Natural Fiber Reinforced Polymer plates (GNFRP) manufactured with hemp

© ASCE 2014

fibers. The plates were used as structural materials for the flexural strengthening of reinforced concrete beams. Computational models were generated to simulate reaction forces, displacements and strains for the beams considered in the studies. Comparisons of experimental and analysis results were presented. The comparison revealed promising findings for considering hemp fibers as reinforcement media for fabricating FRP plates which could be utilized as structural strengthening materials.

ACKNOWLEGEMENT

This work was in part sponsored by the 2012-2013 College of Engineering at California State University at Long Beach Research Initiation and Seed Grant (RISG).

REFERENCES

ABAQUS Inc. Developers. (2011). Simulia ABAQUS (Version No. 6.10.1), Providence, RI. Dassault Systemes.

American Concrete Institute and International Organization for Standardization. (2008). Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary, American Concrete Institute, Farmington Hills, MI.

American Concrete Institute and International Organization for Standardization. (2002). 440.2 R-02: Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures, American Concrete Institute, Farmington Hills, MI.

Hollaway, L., and Teng, J. (2008). Strengthening and rehabilitation of civil infrastructures using fibre-reinforced polymer (FRP) composites, Woodhead Publishing Limited.

Ichhaporia, P. K. (2008). Composites from Natural Fibers, North Carolina State University.

Kahn, M. E., and Levinson, D. M. (2011). Fix it First, Expand it Second, Reward it Third: A New Strategy for America's Highways, Hamilton Project publisher, Washington, D.C.

Karus, M., and Vogt, D. (2004). "European hemp industry: cultivation, processing and product lines." Euphytica, 140(1-2), 7-12.

Kesteloot, S., Djelal, C., Benslimane, I., and Baraka, S. (2011). "Strengthening of sewerage systems with composites plates: numerical optimization." Materials Sciences and Applications, 2(3), 151-162.

Madsen, B., Lilholt, H., Damkilde, L. (2004). Properties of plant fiber yarn polymer composites: an experimental study, Technical University of Denmark.

Sawpan, M. A., Pickering, K. L., and Fernyhough, A. (2011). "Improvement of mechanical performance of industrial hemp fibre reinforced polylactide biocomposites." Composites Part A: Applied Science and manufacturing, 42(3), 310-319.

Teng, J., Chen, J., Smith, S. T. (2002). FRP: Strengthened RC Structures, Pp.266.ISBN 0-471-48706-6, Wiley-VCH, January 2002.

© ASCE 2014

Occupant Satisfaction with Indoor Environmental Quality: A Study of the LEED-Certified Buildings on the Arizona State University Campus

Mounir El Asmar, Ph.D., A.M.ASCE[1], Abbas Chokor, S.M.ASCE[2], and Issam Srour, Ph.D., A.M.ASCE[3]

[1]Assistant Professor, School of Sustainable Engineering and the Built Environment, Arizona State University, P.O. Box 870204, Tempe, AZ 85287-0204, United States; Phone: (480) 727-9023; E-mail: asmar@asu.edu
[2]Graduate Student, School of Sustainable Engineering and the Built Environment, Arizona State University, P.O. Box 870204, Tempe, AZ 85287-0204, United States; Phone: +961-70-399814; E-mail: abbas.chokor@asu.edu
[3]Assistant Professor, Engineering Management, Faculty of Engineering and Architecture, American University of Beirut, P.O. Box 11-0236, Riad El-Solh, Beirut, Lebanon; Fax: +961-1-744462; E-mail: is04@aub.edu.lb.

ABSTRACT

Following a recent surge in the green building movement, several universities now require the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) certification for all their new facilities. This paper investigates the actual occupant satisfaction of LEED-certified higher education facilities through studying seven LEED-certified buildings located on the Arizona State University (ASU) campus in Tempe, AZ. Indoor Environmental Quality (IEQ) occupant satisfaction surveys were used to collect data from over 160 occupants. The surveyed LEED buildings earned, on average, a 77.6% overall satisfaction rating. The results show ASU LEED buildings performed better than the Center for the Built Environment (CBE) benchmark, which is based on 59,359 completed surveys. In addition to comparing the results with other studies, this paper highlights an inconsistency between the LEED points earned for IEQ and the actual level of occupant satisfaction. Additionally, the paper showcases a need for improvement in the USGBC rating system in such a way that correlates the awarded LEED rating with the actual performance of the building during the occupation phase, as opposed to the intended performance during the design and construction stages.

Keywords: education, indoor environmental quality, LEED, occupant satisfaction, thermal comfort.

INTRODUCTION

By making students and instructors' performances a priority, several schools and universities are currently endeavoring to ameliorate their facilities' IEQ by requiring the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED). Recent studies have focused on the effects of space layout and furniture (Cotera 2011), thermal comfort (Mohamed and Srinavin 2005;

© ASCE 2014

Kosonen 2004; Mahbob et al. 2013), indoor air quality (Mahbob et al. 2013; Wyon 2004), lighting level (Abdou 1997; Nicol et al. 2006), acoustic quality (Kaarlela-Tuomaala et al. 2009), water efficiency, cleanliness and maintenance on the well-being, comfort, and production of buildings' occupants (Rashid and Zimring 2008; Haynes 2008; Fisk et al. 2011).

Following a 2005 order by the Governor of Arizona, Arizona State University (ASU) requires, to the fullest extent practicable, Leadership in Energy and Environmental Design (LEED) Silver certification for all new construction of university-owned and operated buildings. Since green design has environmental, economic, and social elements that benefit Arizona State University students, faculty, staff, and other building occupants, ASU has established a Sustainable Design Policy for new construction and major renovation projects on all ASU campuses (Facilities Development and Management 2009).

This paper investigates the actual occupant satisfaction performance of LEED-certified buildings through studying seven LEED-certified buildings located on ASU campus in Tempe, Arizona. First, the study presents the IEQ occupant satisfaction levels of surveyed LEED facilities occupants. Second, it highlights an inconsistency between the LEED points earned for LEED-IEQ category and the actual level of occupant satisfaction. The paper ends with a discussion of recommendations to improve the LEED rating system.

LITERATURE AND BACKGROUND

LEED is a third party certification program that serves as a design and construction tool for new and existing institutional, commercial and residential establishments (Cotera 2011). The creation of LEED was a national response to the increasing social awareness and concerns about the negative environmental impacts that could be generated by buildings including increased energy consumption, depletion of natural resources and waste production, and the increasing reported incidences of the adverse health impacts caused by problems of indoor environmental quality (IEQ) such as sick building syndrome (SBS), multiple chemical sensitivity (MCS), and building related illness (BRI) (Lee and Guerin 2009). As the evidence challenging the long-term effectiveness of green design continues to compound, the pressure has been placed on the USGBC to make improvements to its rating system (Cotera 2011). After developing the pilot version v1.0, LEED has evolved seven versions (v2.0, v2.1, v2.2, v2007, v2008, v2008.2, and v2009) in order to recently reach its latest version: LEED v4. The new version includes new market sector adaptations for data centers, warehouses and distribution centers, hospitality, existing schools, existing retail and mid-rise residential projects – to ensure that LEED fits the unique aspects of any project (USGBC 2013). In addition to the Indoor Environmental Quality category, a building can earn credits from the location and transportation category, the sustainable sites category, the water efficiency category, the energy and atmosphere category, the materials and resources category, and the innovation and regional priority (extra points) to get certified. Depending on the total points earned out of 100 base points, a facility is attributed to one of the four measures: certified (40-49 points), silver (50-59 points), gold (60-79 points), and platinum (80 points and above).

© ASCE 2014

A survey of previous studies illustrates the affiliation of IEQ improvement with the fulfillment of LEED standards. Heerwagen and Zagreus (2005) found that Merrill Center, a LEED certified building, rated third in overall satisfaction among 170 buildings to date, of which ten have a LEED rating. Turner (2006) investigated 11 LEED certified buildings in the Cascadia region and showed that users are satisfied with lighting and air quality of their buildings but unfulfilled with sounds conditions. Abbaszadeh et al. (2006) compared occupant satisfaction in 21 LEED-rated buildings with 160 conventional buildings, and noticed that occupants in LEED-certified buildings were more satisfied with thermal comfort, air quality, office furnishings, cleaning and maintenance, but less satisfied with lighting and acoustics than occupants of conventional buildings. Lee and Guerin (2009) establish that workers in 15 LEED certified buildings are satisfied with cleanliness, maintenance, office furnishing quality and indoor air quality, but dissatisfied with thermal comfort and acoustic quality.

OBJECTIVE AND METHODOLOGY

Among the numerous efforts in the emerging green building movement, the establishment of green building certification systems worldwide is one of the most prominent and ensures a systematic approach to continuing these efforts toward promoting environmental sustainability (Liang et al. 2014). In order to measure users' satisfaction with IEQ factors of seven occupied LEED-certified buildings located on the ASU Tempe campus, this study uses a Post Occupancy Evaluation (POE) survey to investigate satisfaction levels. Later on, this paper compares the results with other studies and showcases an inconsistency between the LEED points earned for IEQ and the actual level of occupant satisfaction.

To address the objectives of this study, seven ASU LEED-certified buildings were selected in Tempe, Arizona, USA. All chosen buildings had been occupied and certified, based on version 2.1 and 2.2 of LEED rating system, for at least one year prior to the start of the data collection in June 2013. According to the old rating system, which encloses version 2.1 and 2.2, there are 69 points divided between six main categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation and design. Therefore, all buildings had been qualified for four levels of accreditation: certified (26-32 points), silver (33-38 points), gold (39-51 points), and platinum (52 points and above). Table 1 summarizes the names, LEED ratings and types, award dates, total earned points as well as the number of points earned under each of the LEED categories.

In this paper, IEQ surveys available in the literature were reviewed, and then the Occupant IEQ survey of the Center for the Built Environment (CBE) at the University of California at Berkeley was used to create an adaptation of Cotera's Occupant Indoor Environment Quality Satisfaction Survey (Cotera 2011). Adapting widely-used surveys would allow for a comparison of the results across several similar studies. Recognizing the performance of LEED-certified buildings is limited to the study of eight key sections: workspace layout, workspace furniture, thermal comfort, indoor air quality, lighting levels, acoustic quality, water efficiency and cleanliness and maintenance in addition to the occupant background information and the overall satisfaction with space (Center for the Built Environment 2010).

Table 1. LEED characteristics of selected buildings

Building name	LEED Rating	LEED type	Award Date	Total points (out of 69)	Sustainable Sites (out of 14)	Water efficiency (out of 5)	Energy & Atmosphere (out of 17)	Materials & Resources (out of 13)	Indoor Environmental Quality (out of 15)	Innovation and Design (out of 5)
Hassayampa Academic Village	Silver	LEED for New Construction	10/18/2009	33	9	3	3	5	8	5
ISTB 1	Gold	LEED for New Construction	3/29/2007	39	9	3	7	5	10	5
ISTB 2	Silver	LEED for New Construction	7/21/2006	33	10	3	5	5	8	2
ISTB 4	Gold	LEED for New Construction	9/7/2012	48	11	3	15	5	9	5
Barrett Honors College	Gold	LEED for New Construction	4/29/2010	39	10	3	7	5	9	5
Global Institute of Sustainability	Silver	LEED for Existing Building	7/23/2009	37	10	3	3	7	9	5
Fulton Center	Certified	LEED for New Construction	8/28/2007	26	8	3	3	4	5	3

In order to attain a real understanding of users' satisfaction, respondents were categorized into three main groups: visitors who used the building for less than three months, students who spent more than three months using the building continuously, and faculty/staff who worked in the selected LEED-certified facility for more than three months. Participants were queried to evaluate their satisfaction with each of the eight survey sections based on a 5-point Likert scale (1 being very dissatisfied, 5 being very satisfied). After splitting the Hassayampa Village into two sub-villages, 20 persons per building responded to the survey, which leads to a total of 160 responses.

Consequently, the average satisfaction percentage was calculated for each of the performance sections after analyzing the collected data. Next, average satisfaction ratings for each section were compared to the CBE's benchmark database, which is a global database of 59,359 occupants' surveys; thus, according to the CBE, a good satisfaction rating is a score greater than the 50th percentile. Finally, the number of LEED points earned for IEQ was compared to the actual level of occupant satisfaction across the surveyed buildings.

PRELIMINARY RESULTS AND DISCUSSION

Of the 160 respondents, 41.9% were faculty/staff, 49.3% were students and 8.8% were visitors. By assuming equal weights for all eight sections, Table 2 shows the average satisfaction percentages by section for each of the seven ASU buildings: the surveyed LEED buildings earned, on average, a 77.67% rating across all sections.

Table 2. Survey preliminary results

Building	Space Layout	Space Furniture	Thermal comfort	Indoor Air quality	Lighting level	Acoustic Quality	Water Efficiency	Cleanliness& Maintenance	Overall Satisfaction	Average
ISTB 4	79.50%	77.00%	63.50%	81.50%	76.25%	65.33%	70.00%	84.33%	82.50%	**75.55%**
Global Institute of Sustainability	80.25%	85.00%	68.00%	77.00%	84.75%	76.33%	82.00%	85.33%	83.50%	**80.24%**
ISTB 1	81.00%	82.75%	73.00%	83.50%	78.75%	60.33%	77.00%	82.00%	83.50%	**77.98%**
Fulton Center	86.25%	81.75%	71.50%	83.00%	80.25%	72.33%	79.00%	94.33%	88.50%	**81.88%**
ISTB 2	75.75%	75.00%	73.00%	78.00%	68.75%	67.67%	74.00%	78.67%	80.00%	**74.54%**
Barrett Honors College	81.50%	80.00%	74.00%	76.00%	79.25%	72.33%	69.00%	83.33%	87.00%	**78.05%**
Hassayampa Academic Village	78.25%	78.75%	74.00%	77.25%	75.38%	77.17%	70.00%	79.67%	78.75%	**76.58%**
Average	**80.09%**	**79.88%**	**71.38%**	**79.19%**	**77.34%**	**71.08%**	**73.88%**	**83.42%**	**82.81%**	**77.67%**

Figure 1 provides a graphical illustration of the difference in performance throughout the eight survey questions across the selected buildings. Although the buildings did not achieve the recommended 80% target for thermal comfort according to the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 55, ASU LEED buildings performed much better than the CBE national benchmark based on 59,359 participants.

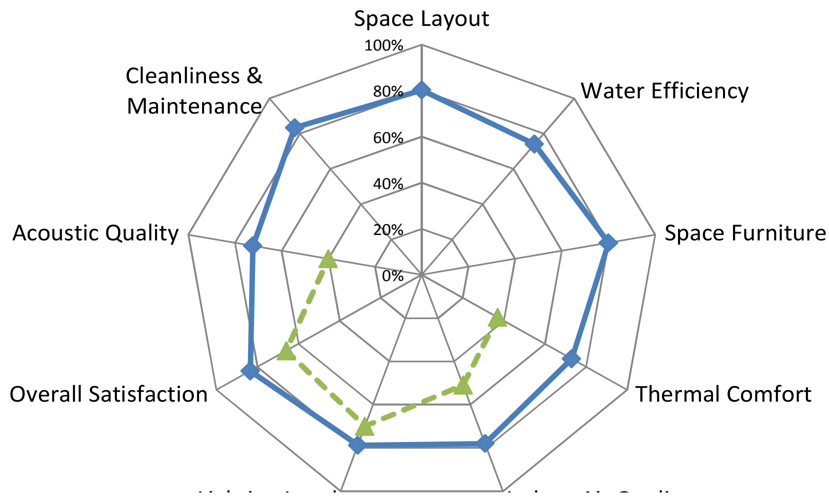


Figure 1. Comparison of ASU and CBE occupant satisfaction results

© ASCE 2014

In addition, results showcased an inconsistency between building's earned points on the LEED scale and the level of user satisfaction. Figure 2 presents the variation of average level of satisfaction according to the IEQ earned LEED points. In instance, the occupants of the *Fulton Center* that earned only 5 out of 15 possible points on IEQ were much more satisfied than the occupants of *ISTB 1* that achieved 10 points on IEQ.

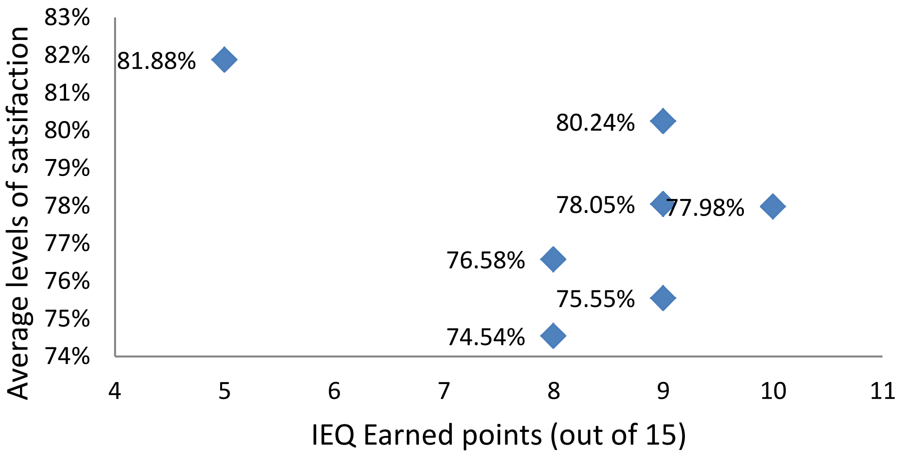


Figure 2. Average levels of occupant satisfaction versus IEQ points earned

For most LEED certifications, once a building is certified, it is certified for life. Though many steps are carefully taken to ensure that these buildings meet the required standards during the design and construction processes, none are taken to verify that the buildings are still maintaining their efficient performance levels after certification (Cotera, 2011). This final result is in line with several calls from the authors to improve the LEED rating system, mainly by awarding the rating based on the actual performance of the facility (e.g.; Menassa et al. 2012).

CONCLUSION

This paper investigated the actual occupant satisfaction of LEED-certified buildings through studying seven LEED-certified buildings located on the Arizona State University campus in Tempe, AZ. The surveyed LEED buildings earned, on average, a 77.6% overall satisfaction rating, which is a little short of the 80% target recommended by USGBC, but these ASU LEED buildings performed a lot better than the Center for the Built Environment (CBE) national benchmark, which is based on 59,359 completed surveys. Additionally, the dataset collected for this study shows that an increase in IEQ points earned in LEED is not necessarily securing a superior occupant satisfaction with indoor environmental quality for higher education facilities. The study's findings call into question the effectiveness of the IEQ points awarded as part of the LEED rating system to help reduce absenteeism and increase the productivity of students, staff, and faculty in higher educational facilities. The results

© ASCE 2014

presented in this paper are only preliminary, and a larger number of respondents are currently being targeted to increase the sample size and validate these findings.

REFERENCES

Abbaszadeh, S., Zagreus, L., Lehrer, D., and Huizenga, C. (2006). Occupant satisfaction with indoor environmental quality sin green building. *Healthy Buildings Conference*. Lisbon, Portugal.

Abdou, O. (1997). Effects of luminous environment on worker productivity in building spaces. *J Archit Eng*, 33(3):124e32.

Facilities Development and Management. (2009). *ASU Sustainable Design Policy*. Tempe: Arizona State University.

Center for the Built Environment. (2010). *Occupant IEQ Survey Demo*. University of California Berkeley.

Cotera, P. (2011). *A Post-Occupancy Evaluation: To What Degree do LEED Certified Buildings Maintain Their Sustainable Integrities Over Time?* University of Florida.

Fisk, W., Black, D., and Brunner, G. (2011). Benefits and costs of improved IEQ in U.S. offices. *Indoor Air*, 21(5):357e67.

Haynes, B. (2008). The impact of office comfort on productivity. *J Facil Manag*, 6:37e51.

Heerwagen, J., and Zagreus, L. (2005). *The human factors of sustainable building design: post occupancy evaluation of the Philip Merrill Environmental Center*. Berkeley: Center for the Built Environment, UC.

Kaarlela-Tuomaala, A., Helenius, R., Keskinen, E., and Hongistoa, V. (2009). Effects of acoustic environment on work in private office rooms and open-plan offices-longitudinal study during relocation. *Ergonomics*, 52:1423e44.

Kosonen R, T. F. (2004). The effect of perceived indoor air quality on productivity loss. *Energy Build*, 36:981e6.

Kosonen, R., and Tan, F. (2004). Assessment of productivity loss in air-conditioned buildings using PMV index. *Energy Build*, 36:987e93.

Lee, Y., and Guerin, D. (2009). Indoor Environmental Quality Related to Occupant Satisfaction and Performance in LEED-certified Buildings. *Indoor and Built Environment*, 18: 293.

Liang, H.-H., Chen, C.-P., Hwang, R.-L., Shih, W.-M., and Lo, S.-C. (2014). Satisfaction of occupants toward indoor environment quality of certified green office buildings in Taiwan. *Building and Environment*, 72:232e242.

Mahbob, N., Kamaruzzaman, S., Salleh, N., and Sulaiman, R. (2013). Correlation and regression studies of indoor environmental quality (IEQ), human productivity,comfort and stress level in office buildings. *Adv Sci Lett*, 19(1):342e5.

Menassa, C., Mangasarian, S., El Asmar, M., and Kirar, C. (2012). Energy Consumption Evaluation of U.S. Navy LEED-Certified Buildings. *J. Perform. Constr. Facil.*, 26:46-53.

Mohamed, S., and Srinavin, K. (2005). Forecasting labor productivity changes in construction using the PMV index. *Int J Ind Ergon*, 35:345e51.

© ASCE 2014

Nicol, F., Wilson, M., and Chiancarella, C. (2006). Using field measurements of desktop illuminance in European offices to investigate its dependence on outdoor conditions and its effect on occupant satisfaction, and the use of lights and blinds. *Energy Build*, 38:802e13.

Order, E. (2005). *Implementing renewable energy and energy efficiency in new state buildings*. Pheonix.

Rashid, M., and Zimring, C. (2008). A review of the empirical literature on the relationships between indoor environment and stress in health care and office settings problems and prospects of sharing evidence. *Environ Behav*, 40(2):151e90.

Turner, C. (2006). *LEED building performance in the Cascadia region: a post occupancy evaluation report*. Cascadia Region Green Building.

USGBC. (2013). *LEED v4 for Building Design and Construction* .

Wyon, D. (2004). The effects of indoor air quality on performance and productivity. *Indoor Air*, 14(7):92e101.

© ASCE 2014

Assessing LEED versus non-LEED Energy Consumption for a University Campus in North America: A Preliminary Study

Claire TILTON[1] and Mounir EL ASMAR[2], Ph.D.

[1]FURI Undergraduate Research Student, School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ 85287; claire.tilton@asu.edu
[2]Assistant Professor, School of Sustainable Engineering and the Built Environment, Arizona State University, PO Box 875306, Tempe, AZ 85287-5306; PH (480) 727-9023; FAX (480) 965-1769, email: asmar@asu.edu

ABSTRACT

Today, buildings contribute about 40% of the world's carbon dioxide emissions and consume about 70% of the electricity produced in the United States. Due to this high rate of consumption, governments and numerous organizations have worked avidly on ways to design, build, and recognize high-performance or sustainable buildings. The Leadership in Energy & Environmental Design (LEED) rating system is intended to award buildings that "save energy, use fewer resources and reduce pollution". This paper is part of a study that aims to test the following hypothesis: LEED certified buildings save energy in their operations phase. The research objective was accomplished by investigating LEED-certified buildings on a university campus and measuring their energy performance against that of non-LEED building counterparts. Energy performance was calculated in terms of energy unit intensity (EUI) by combining heating, cooling, and electricity data from the metered buildings on campus. Preliminary data show LEED-certified dormitory buildings seem to have lower energy consumption as compared to non-LEED buildings; LEED-certified research buildings seem to use more energy than their non-LEED counterparts; and LEED office buildings are not displaying major differences in energy performance. However, the use and research intensity of these buildings, and its effect on energy consumption have not been investigated yet, and statistical analysis is currently being completed to verify these preliminary conclusions.

INTRODUCTION

In line with several organizations' sustainability initiatives in the U.S., a recent trend for many university campuses has been to require new buildings to conform with the Leadership in Energy and Environmental Design (LEED) certification by the United States Green Building Council (USGBC). The *Energy & Environment* category of the LEED building rating system accounts for about a third of the LEED points available for certification, and one major reason facility owners require LEED is the expectation and assumption that certified buildings reduce energy consumption in comparison to traditional buildings. This study tests this assumption by investigating the impact of LEED certification on the energy consumption of university buildings.

The first step in the study is reviewing the state of knowledge on existing performance studies that targeted other types of LEED certified building. Specifically, studies that compare LEED certified buildings to their non-LEED counterparts are summarized. When the USGBC started the LEED rating system in the 1990's there did not exist a sufficient amount of post-

© ASCE 2014

occupancy energy data from certified buildings to conduct significant research. In contrast, with today's numerous mandates requiring LEED certification and the increased amount of metering, more data is available to test the performance of LEED certified building.

Turner (2006) performed a study on LEED buildings in the Cascadia region and determined LEED buildings are performing better than baseline values. Additionally, Turner and Frankel (2008) conducted a study that concluded LEED buildings have a 24% lower energy unit intensity (EUI) than their national counterparts. However, researchers Newsham et al. (2009) and Scofield (2009), using the same data as Turner and Frankel (2008), later scrutinized the initial findings and found that LEED certification was not correlated with the energy consumption levels. Similarly, Menassa et al. (2012) investigated the energy consumption of the U.S. Navy's LEED certified buildings. These facilities were required to become LEED certified to comply with an Executive Order that aims at reducing energy consumption by 30 percent. Menassa et al. compared these LEED buildings to non-LEED counterparts and found the majority of the Navy LEED buildings did not achieve expected electricity consumption savings, and several consumed more energy than national averages.

RESEARCH OBJECTIVES

Based on the existing literature, it is not clear whether LEED certified buildings have a superior energy performance compared to non-LEED buildings. The findings of the studies that attempted to test the correlation between LEED certification and energy performance are not all in agreement. Some authors showed LEED buildings were consuming less than their baseline counterparts; however, other authors showed the exact opposite with LEED buildings not saving energy over time. The main problem here is that the correlation between a building's LEED certification and its energy performance over time doesn't seem to be fully understood. Therefore, the objective of this research study is to collect and analyze additional data to understand actual LEED building energy performance as compared to non-LEED building counterparts. The overall research question is: "*Are LEED buildings outperforming non-LEED buildings in terms of energy consumption?*" By collecting the metering data of all buildings on a university campus for the past 4 years (specifically kWh of electricity, mmBTU of heating, and tonHr of chilled water), the energy performance of each building will be studied. This paper will present the collected data to date, in anticipation of the final statistical analysis that is currently ongoing.

METHODOLOGY

After identifying the buildings, they were divided by square footage for each type of usage, and then their metered energy data was collected. Different buildings have different functions, and therefore not all are expected to use the same amount of energy. In this study, it was pivotal to differentiate buildings by usage type. These were classified into: student housing, office, and research facilities, by using the gross square footage and the granular square footage data for each building. Both LEED and non-LEED buildings with similar type and square footage were placed in the same category for adequate comparisons. Then four years of building metering information was collected. Some of the LEED certified buildings are relatively new and have only been metered since their construction. Therefore, less than four years of data is available for some of these buildings. The metering data collected includes kWh of electricity,

© ASCE 2014

mmBTU of heating, tonHr of chilled water, and the total mmBTU of energy (which combines heating, cooling, and electricity consumption). The data was recorded on a monthly basis. As expected when collecting data over a long period of time, some information was omitted due to faulty readings: a few meters were not collecting information, collecting erroneous information, or only collecting information for part of the month. However, out of all the data, only 0.79% was omitted. Specifically, for office buildings one month of total energy data was omitted for one building, for student housing buildings 12 months of total energy data were omitted out of 594 data points (all from one building), and for research buildings no data was omitted. Energy Unit Intensity (EUI) is a unit of measure in kBTU/GSF. The EUI was calculated for each building, both LEED and non-LEED. Furthermore, electricity, heating, and cooling values were normalized per building area in gross square feet. Values were plotted by month and buildings were classified based on LEED certification.

PRELIMINARY FINDINGS

In order to achieve LEED certification, a building must amass a certain number of points in different categories. A higher number of points will be rewarded with a better rating. The rating hierarchy from highest to lowest is as follows: platinum, gold, silver, and certified. In this collected dataset, Building M is certified LEED Platinum. Building L, N, O and A are LEED Gold. Buildings B, C, P and Y are LEED Silver. Lastly, Building C is LEED Certified. Out of these LEED buildings on the university campus, three are residential, five are for research, and two mainly contain offices. The remaining buildings are similar non-LEED certified counterparts. All the studied buildings are represented in Table 1.

TABLE 1: SURVEYED CAMPUS FACILITIES

Building Use	Building	LEED Rating	Building Use	Building	LEED Rating	Building Use	Building	LEED Rating
Student Housing	A	Gold	Research	L	Gold	Office and Classroom	Y	Silver
	B	Silver		M	Platin.		Z	Certif.
	C	Silver		N	Gold		AA	NA
	D	NA		O	Gold		AB	NA
	E	NA		P	Silver		AC	NA
	F	NA		Q	NA		AD	NA
	G	NA		R	NA		AE	NA
	H	NA		S	NA		AF	NA
	I	NA		T	NA			
	J	NA		U	NA			
	K	NA		V	NA			
				W	NA			
				X	NA			

Figure 1 shows the data for LEED (shown in green) and non-LEED (in red) student housing buildings, illustrating considerable energy savings for the LEED certified facilities. However, Figure 2 shows LEED office buildings did not exhibit a clear trend but included some of the low-performers in this dataset. Finally, Figure 3 shows the total energy consumption for research buildings was higher for some of the LEED certified buildings, which might be caused by the type of energy intensive new research laboratories installed in some of these facilities.

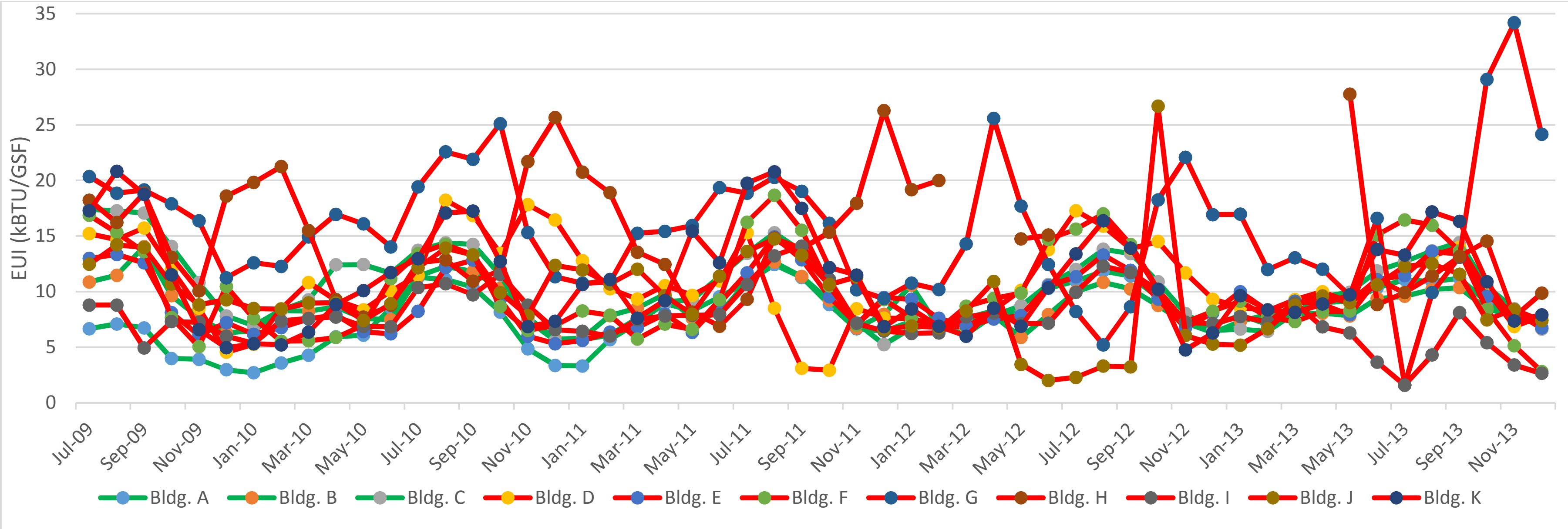


FIGURE 1: MONTHLY EUI OF STUDENT HOUSING BUILDINGS

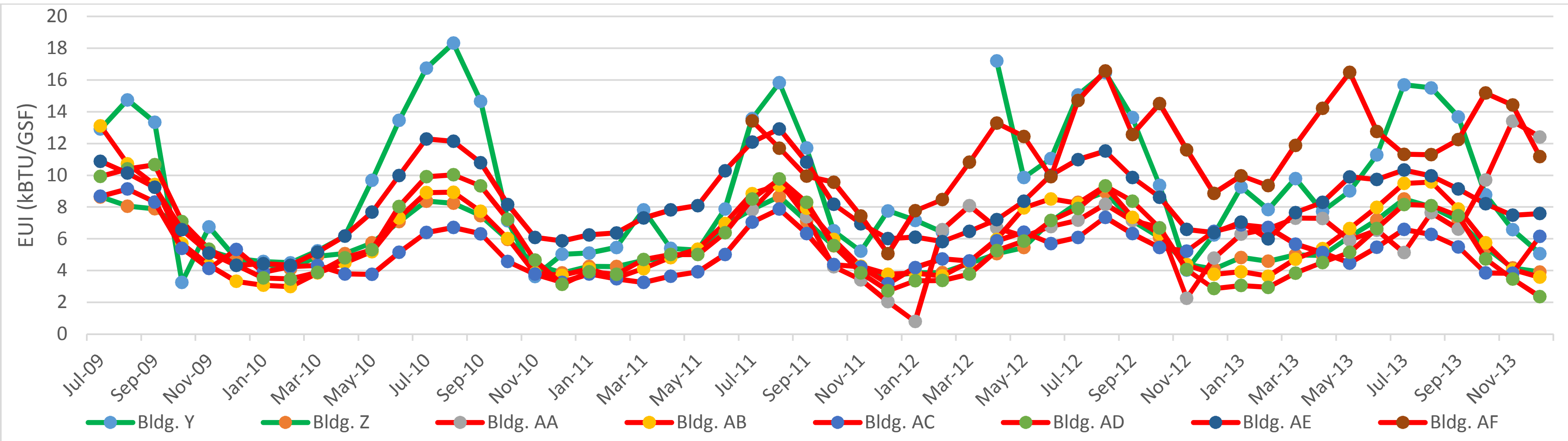


FIGURE 2: MONTHLY EUI OF OFFICE BUILDINGS

© ASCE 2014

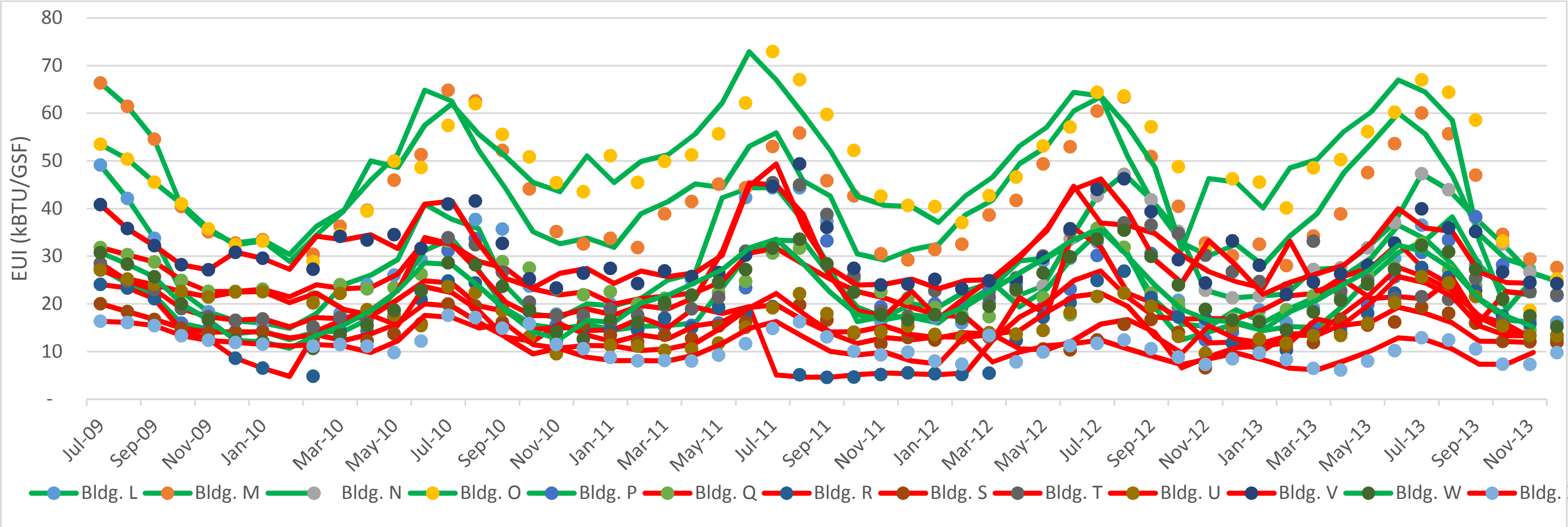


FIGURE 3: MONTHLY EUI OF RESEARCH BUILDING

© ASCE 2014

CONCLUSION

Preliminary data shows the studied sample of LEED student housing buildings was on the lower end of the energy spectrum compared to non-LEED counterparts, LEED research buildings appear to have a higher usage than their counterparts, and there is no clear trend for LEED office buildings. However, this is just the first high-level look at the energy consumption data, and conclusions should not be made before analyzing the causes of these differences at a micro level. In fact, the statistical analysis of the observed differences was still underway at the time of this writing, and once completed it will test the significance of the differences and their possible causes. One variable studied is the type of building activities and their intensity (e.g. energy intensive research laboratories); another variable is the number of points received in the *Energy and Atmosphere* category, which is a reflection of the focus on energy in the design of the building. In fact, buildings can get certified by focusing on other categories and only meeting the minimum requirements of the energy category. There are indeed several variables that can impact the energy performance of a facility, and understanding these is crucial for building owners, especially those with strong commitments to become carbon neutral.

REFERENCES

Menassa, C., Mangasarian, S., El Asmar, M., & Kirar, C. (2012). Energy Consumption Evaluation of U.S. Navy LEED-Certified Buildings. J. Perform. Constr. Facil., 26:46-53.

Newsham, G.R., Mancini, S., and Birt, B.J. (2009). "Do LEED-certified buildings save energy? Yes, but…" *Energy and Buildings*, Volume 41, Issue 8, pp. 897–905.

Scofield, J (2009). "Do LEED-certified buildings save energy? Not really…" *Energy and Buildings* 41(12), 1386-1390.

Turner, C. (2006). "A Post-Occupancy Look at LEED Building Performance." *Heating/Piping/Air Conditioning Engineering: HPAC*78.10 (2006): 26,28,30,32-33. *ProQuest*.

Turner, C. and Frankel, M. (2008). "Energy performance of LEED for new construction buildings." New Buildings Institute (NBI) Rep. for US Green Building Council (USGBC),

© ASCE 2014

Preliminary heat transfer analysis for a large extensive green roof

Mallory N. Squier[1], J.B. Ahmad, Zhi Cui, and Cliff I. Davidson[2]

[1] Department of Civil and Environmental Engineering, Syracuse University, 151 Link Hall, Syracuse, NY 13210; email: mnsquier@syr.edu
[2] Department of Civil and Environmental Engineering, Syracuse University, 151 Link Hall, Syracuse, NY 13210; PH (315) 443-4287; email: davidson@syr.edu

ABSTRACT

Extensive green roofs provide many ecosystem services lacking in the urban environment and are a widely implemented green infrastructure solution for urban stormwater. Yet few studies consider the performance of large green roofs after installation. This study presents initial data covering a few days in fall 2013 collected at a large exterior green roof (0.56 ha) in Syracuse, NY. Temperature sensors were installed throughout the layers of the roof during construction. Daily temperature follows an approximate sine curve with amplitude decreasing as a function of depth into the roof. Analysis of temperature within the roof layers indicates lag times of 3-4 hours relative to air temperature, illustrating slow heat transfer through the layers. Initial observations of growth medium moisture conditions show changing thermal properties as moisture content changes. Future work will consider heat transfer in all seasons and the influence of building HVAC system data on the roof temperature profile.

INTRODUCTION

With the advent of urbanization, many ecosystems were dramatically altered. Today with increased costs for aging infrastructure and maintenance, the value of the once-free ecosystem services are recognized as inherent cost savings when urban green space is preserved or ecosystems are reconstructed. Green infrastructure improves upon traditional grey infrastructure by restoring ecosystem services. A green roof, one type of green infrastructure, may provide multiple ecosystem services including (1) decreases in stormwater runoff (Berghage et al. 2009; Carson et al. 2013) (2) reductions in the urban heat island effect (Rosenzweig et al. 2009; Saiz et al. 2006), and (3) increases in wildlife habitat and urban biodiversity (Baumann 2006; Brenneisen 2006; Grant 2006).

The main motivation of this research is hydrologic in nature, with the aim of enhancing our understanding of the water mass balance over a large extensive green roof, but our study also investigates the components of the energy balance. A more complete understanding of the mass and energy balances on a green roof will inform future design decisions looking to optimize for certain ecosystem service. The results of our work at field-scale will also support significant works completed at the lab-scale.

© ASCE 2014

Our research is in an early phase; this report focuses on (1) heat transfer through layers of the green roof and (2) the impact of moisture on heat transfer through the growth medium on the green roof.

EXPERIMENTAL SITE DESIGN

Site description

The study site (Figure 1) is located on the roof of the Nicholas J. Pirro Convention Center (the OnCenter) in downtown Syracuse, New York (43.044N, 76.148W). The 60,000 sq. ft. (0.56 ha) extensive green roof was retrofitted to the existing building in fall 2011. The roof profile is shown in Figure 2. Sensors A, B, and C are embedded within the constructed roof, while sensors labeled G are located about midway within the 3 inch layer of growth medium. Sensors labeled Y are mounted against the ceiling of the exhibit hall underneath the roof. There are five locations of the temperature profile A-B-C-G as shown in Figure 3, and there are three Y sensors on the ceiling underneath. All of these sensors are from Campbell Scientific (CS 109). The building is surrounded by taller buildings within a few hundred meters to the north, parking garages of equal height to the east and west, and 1-2 story residences and schools to the south, allowing for several kilometers airflow over obstacles with small height that the roof when winds are from the south. The large size of the roof and its location enhance our opportunity for accurate

Figure 1. The OnCenter green roof looking South during a summer bloom

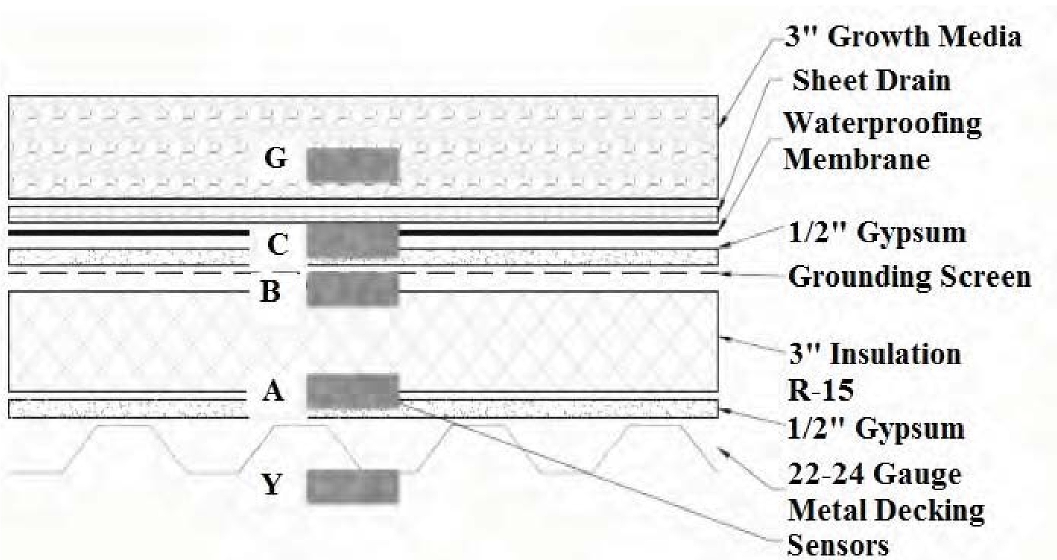


Figure 2. Green roof layers and temperature sensor positions

© ASCE 2014

measurements of airflow and related atmospheric parameters by minimizing edge effects and providing adequate fetch for southerly winds. A reference roof, currently being instrumented, is located on the roof of the Onondaga County Justice Center in downtown Syracuse, NY (43.046N, 76.147W).

Experimental Design

The experimental setup includes a Campbell Scientific (CS) weather station that records hourly wind speed and direction (RM Young 03002), air temperature and relative humidity at two heights in profile (Vaisala HMP 155A), solar radiation (LI-COR LI200X) and surface temperature (Apogee SI-111). These sensors have been placed on the two tripods shown in Figure 3. Year-round precipitation is measured at five-minute intervals using a 0.25 mm resolution AEPG 1000 Belfort weighing rain gauge equipped with a heated orifice and double alter shield, positioned north of the weather station tripod as illustrated in Figure 3. Additionally, warm weather rainfall is measured hourly by a 0.1 mm resolution TE 525 tipping bucket (Texas Electronics) mounted on the shorter of the two tripods shown in Figure 3. Runoff from the roof will eventually be measured using three Badger M-2000 electromagnetic flowmeters following a drop in pipe diameter from 10 to 4 inches (Figure 4). Five water content reflectometers (CS 616) will be installed at various locations in the growth medium. Calibration of the reflectometers positioned within this growth medium was completed in summer 2012.

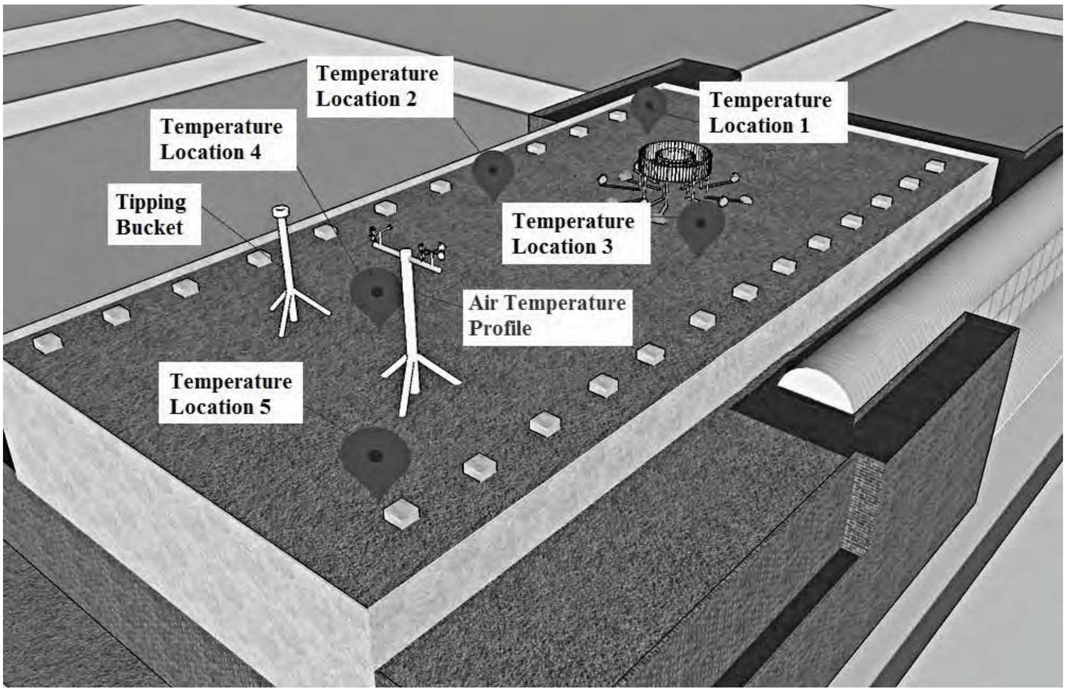


Figure 3. Weather equipment and temperature profile locations on the OnCenter green roof. The building is positioned along a North-South axis, with the wall in the lower left facing South. There are thirteen stormwater drains along the East side of the roof, and twelve along the West side.

© ASCE 2014

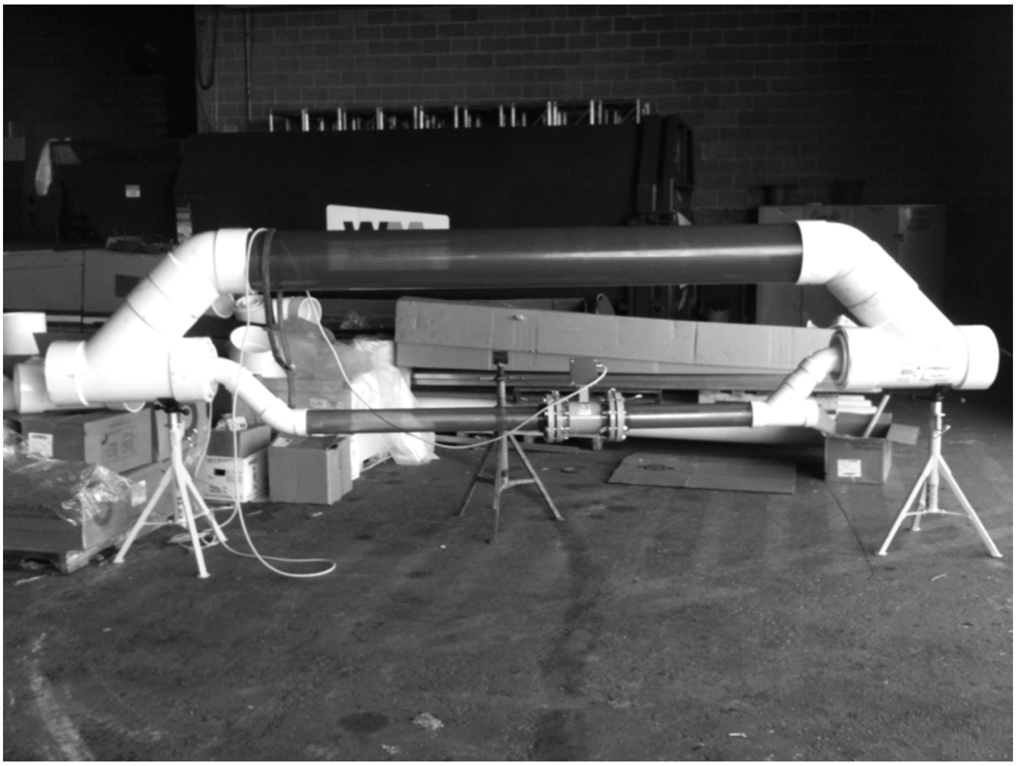


Figure 4. Badger M-2000 electromagnetic flowmeter before installation

PRELIMINARY HEAT TRANSFER ANALYSIS

Heat Transfer through Roof Layers

Daily temperatures follow a cycle resembling a sine function, a result of daily solar input. Hourly averages of solar radiation for a three-day period, September 18-20, 2013, are shown in Figure 5. Three profiles of average hourly temperatures through the roof layers are shown in Figure 6. Only temperature profiles at locations 1, 2, and 5 are shown due to missing or spurious data at the other two locations during the three-day period. For the purposes of this study a sunny, dry three-day period in September was chosen to illustrate heat transfer through multiple layers of the green roof. Data for each layer and location were normalized to the 24-hour average temperature for each of the three days and fit to the sine wave below, where x_c is the phase shift, A is the amplitude, w is the period, and y_0 is the offset (OriginLab 2013). Parameters from this sine fit are shown in Table 1. Values for y_0 are effectively zero.

$$y = y_0 + A \sin\left(\pi \frac{x - x_c}{w}\right)$$

© ASCE 2014

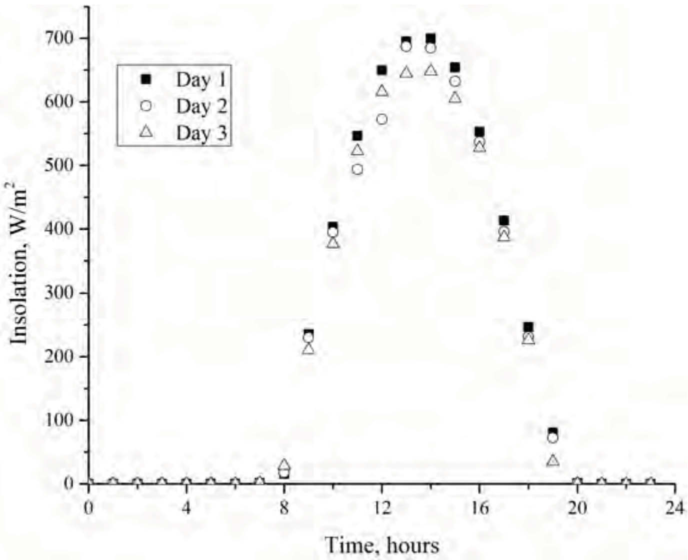


Figure 5. Insolation measured onsite September 18-20, 2013

Moving vertically down through the layers the amplitude decreases. A noticeable difference in amplitude is seen between layers G and C, separated by approximately 1.5" of growth medium, a drainage sheet and waterproof membrane. A much larger difference is seen between layers B and A, separated by 3" of insulation. Layers C and B have similar amplitudes as they are only separated by ½" gypsum board. Temperatures at layers A and Y show little variability through the day. It is unclear how much these two layers are affected by solar input relative to the building HVAC system. Future work will include the HVAC operations data, which should help to explain these patterns.

A comparison of fitted sine curves for September 25-26, 2013 at location 5 from each layer as well as air temperatures above the roof, are shown in Figure 7. The air temperature sensors are located at 9 feet above the roof (H) and 1 foot above the roof (L) in profile. A cutout of Figure 7 is enlarged to show the relative time of the maxima of these curves in Figure 8. Hourly values of the time lags through each layer are given in Table 1.

We would expect the ideal daily air temperature for the days in September to peak at about 3:30 pm. This is roughly the time we see both sensors H and L in the air temperature profile reach their peaks. Interactions governing air temperature profiles are complex, resulting from upwind mixing conditions, solar input causing heat to rise from the roof, and other factors. Future modeling will focus on predicting the air temperature profile over the roof. The difference in timing of the peaks between the air temperature and the growth medium, layer G, is substantial. While the air temperature peaks in the mid-afternoon, this is not reflected in the growth medium until 3.37 hours later at about 6:50 pm EST. By this time solar input has dramatically reduced, reaching zero in the next hour, as seen in Figure 5. The growth medium

© ASCE 2014

both above and below the sensor is responsible in part for the lag times seen between the air temperature and layer G, and layers C and G, respectively. Moving vertically down through the roof, lag times increase from layer G to layer A, as reported in Table 1.

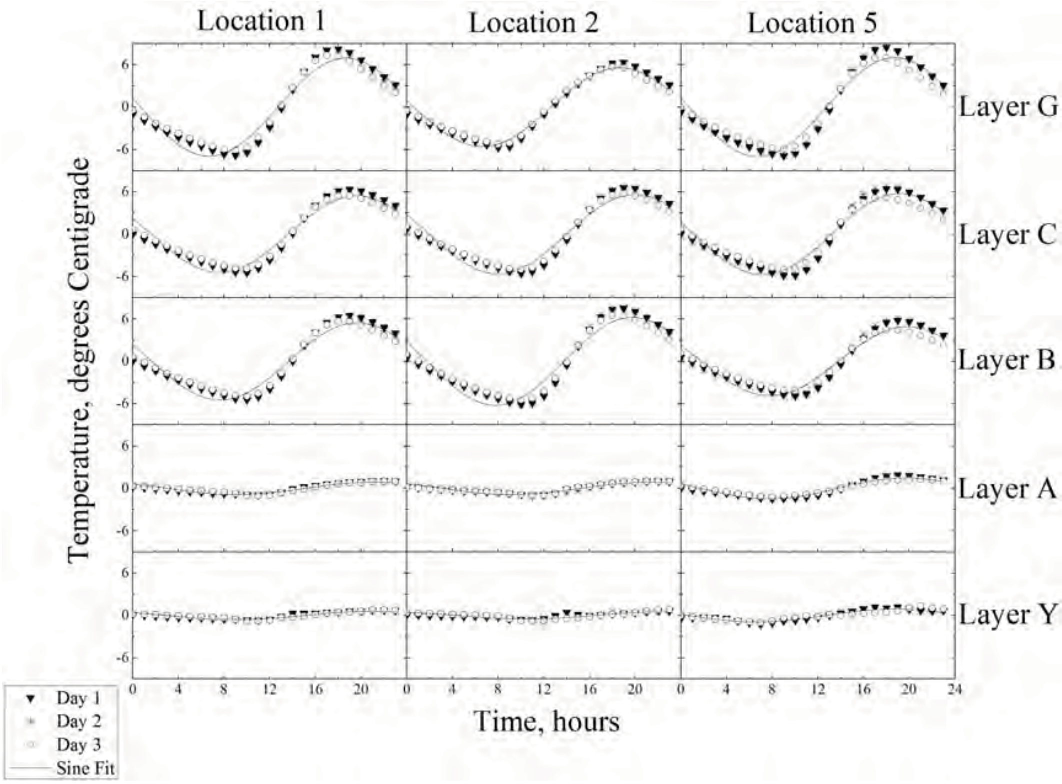


Figure 6. Daily temperature variation at three profile locations for 18-20 September 2013

Table 1. Sine fit parameters for two locations on 25-26 September 2013

	x_c	w	A	Adj. R-Square	Phase shift, hours
5G	12.887	12	6.639	0.938	-3.374
5C	13.290	12	5.785	0.940	-3.479
5B	13.968	12	4.850	0.940	-3.657
5A	14.757	12	1.349	0.920	-3.863
2G	12.805	12	6.065	0.938	-3.352
2B	13.772	12	4.768	0.945	-3.606
2C	13.852	12	4.767	0.938	-3.627
2A	-7.890	12	0.771	0.782	2.066

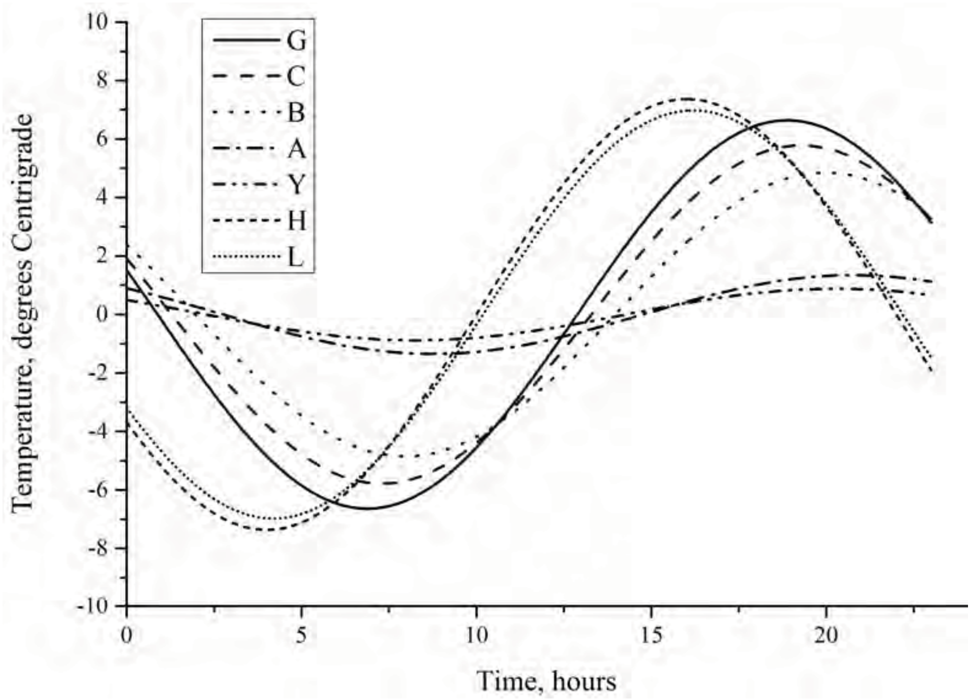


Figure 7. Daily temperature sine fit for 25-26 September 2013 at location 5

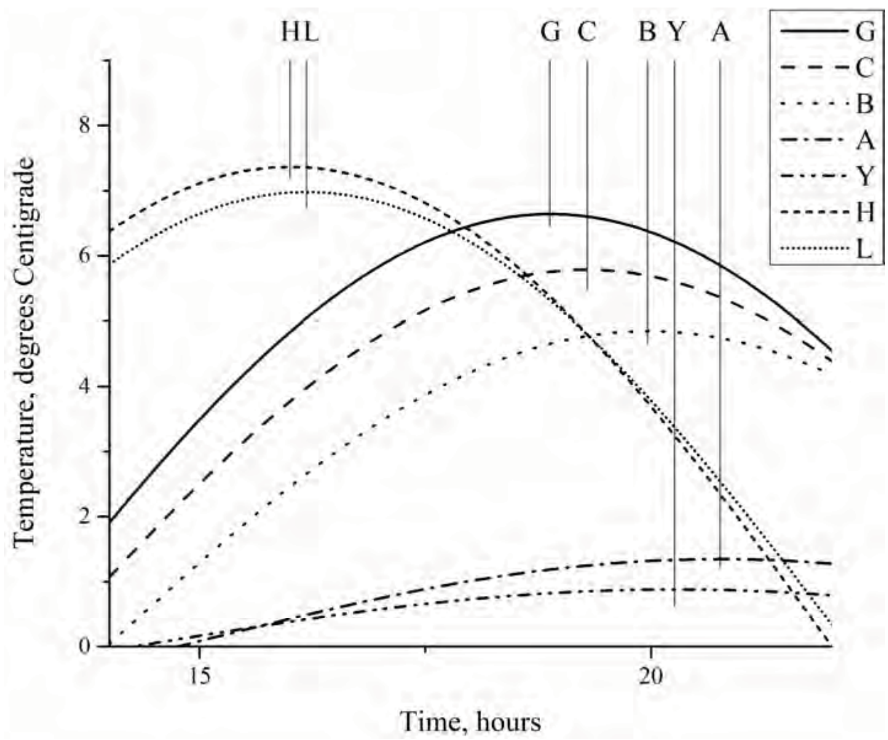


Figure 8. Daily temperature sine fit peaks for 25-26 September 2013 at location 5

© ASCE 2014

Effect of soil moisture on thermal properties

The thermal properties of soil vary based on multiple factors including composition and moisture state due to diverse natural conditions. Growth media for green roof applications are generally very different in composition from natural soils and reflect different thermal properties. One study in the western U.S. found thermal conductivities of multiple growth media vary only slightly relative to the natural range reported in the literature, while the specific heat capacities of growth media were approximately one-half of those for natural soils reported in the literature (Sailor et al. 2008). Increasing moisture in the growth medium increases its thermal conductivity, resulting in increased heat loss in the growth medium layer. Figure 9 shows the temperature in the growth medium, layer G, and directly below, in layer C, for one day in September 2013.

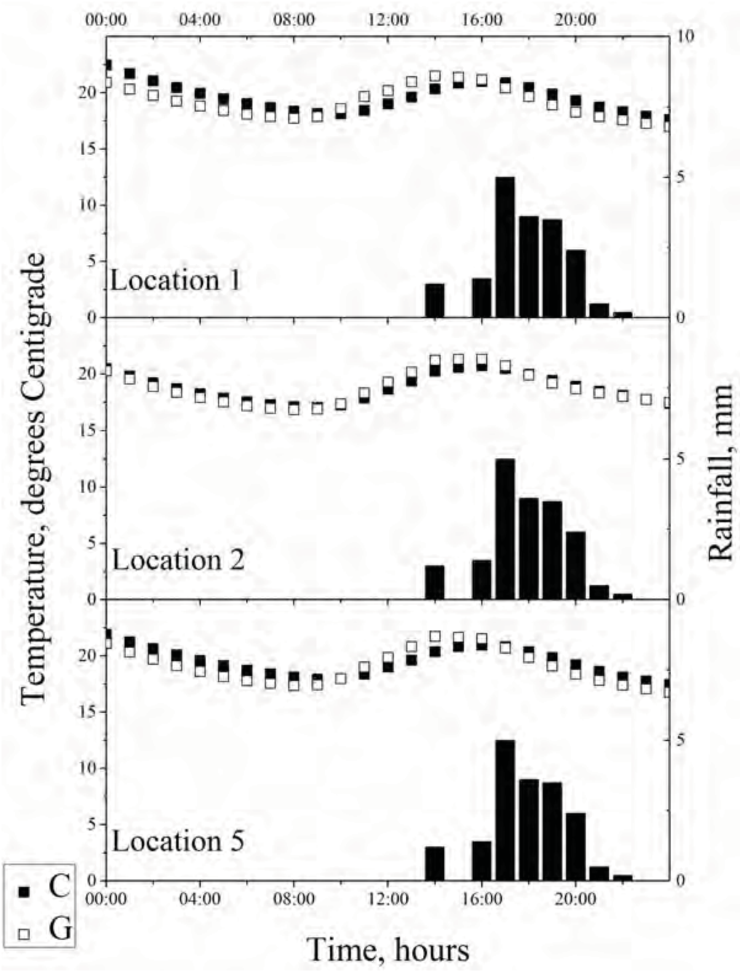


Figure 9. Temperature in two layers at three locations during a rainstorm on 21 September 2013

© ASCE 2014

Beginning at midnight on the 21st, layer G is slightly cooler than layer C. As the sun rises, layer G begins to warm before layer C, reaching a peak temperature first at approximately 2pm when the first precipitation begins. As the soil moisture increases and the sun gets lower in the sky, the temperature of G falls below C by 5 pm EST.

CONCLUSIONS

Our temperature data clearly illustrate the movement of heat downward through the roof layers, shown by increasing lag times. Initial investigation of the effect of moisture on growth medium thermal properties suggests that the thermal conductivity of our growth medium increases with increasing soil moisture. This study is merely a first step in building a heat transfer model of our extensive green roof. The next steps in this research will include detailed analysis of interior HVAC system data. We plan to consider factors that influence heat transfer on the roof, including soil moisture and seasonal variations. Finally, after the development of complete steady-state heat transfer model, we will expand our model to include change in heat transfer over time.

REFERENCES

Baumann, N. (2006). "Ground-nesting birds on green roofs in Switzerland: Preliminary observations." *Urban Habitats*, 4(1), 37–50.

Berghage, R. D., Beattie, D., Jarrett, A. R., Thuring, C., Razaei, F., and O'Connor, T. P. (2009). *Green Roofs for Stormwater Runoff Control By*. US EPA.

Brenneisen, S. (2006). "Space for urban wildlife: designing green roofs as habitats in Switzerland." *Urban Habitats*, 4(1), 27–36.

Carson, T. B., Marasco, D. E., Culligan, P. J., and McGillis, W. R. (2013). "Hydrological performance of extensive green roofs in New York City: observations and multi-year modeling of three full-scale systems." *Environmental Research Letters*, 8(2), 024036.

Grant, G. (2006). "Extensive green roofs in London." *Urban Habitats*, 4(1), 51–65.

OriginLab. (2013). "Origin ." Northhampton, MA.

Rosenzweig, C., Solecki, W., Parshall, L., Barry, L., Cox, J., Goldberg, R., Hodges, S., Gaffin, S., Slosberg, R., Savio, P., Dunstan, F., and Watson, M. (2009). "Mitigating New York city's heat island." *Bulletin of American Meteorological Society*, 90, 1297–1312.

Sailor, D. J., Hutchinson, D., and Bokovoy, L. (2008). "Thermal property measurements for ecoroof soils common in the western U.S.." *Energy & Buildings*, 40(7), 1246–1251.

Saiz, S., Kennedy, C., Bass, B., and Pressnail, K. (2006). "Comparative Life Cycle Assessment of Standard and Green Roofs." *Environmental Science & Technology*, 40(13), 4312–4316.

© ASCE 2014

A Sustainability Rating System for Roads in Developing Countries

Robert Montgomery[1], PhD; Howard Schirmer, Jr. [2], P.E., FASCE, ENV-SP; and Art Hirsch[3], LEED AP, ENV-SP, ENV-PV

[1]Sustainable Development Department, Latin America and Caribbean Region, World Bank, 1818 H Street NW, Washington DC 20433; PH: +1 (202) 473-8968; FAX: +1 (202) 522-3540; Email: montgomery1@worldbank.org

[2]Transnational Associates, Inc., 4100 E. Quincy Ave., Englewood, CO 80113-5051; PH: +1 (303) 221-0360; FAX: +1 (303) -221-0359; Email: hschirmer@transnationalassociatesinc.com

[3]TerraLogic, LLC, 5766 Flagstaff Road, Boulder, CO 80302; PH: +1 (303) 786-9111; Email: AHirsch@TerraLogicss.com

ABSTRACT

Growth, prosperity and economic development for developing countries are dependent upon reliable and safe transportation systems. Road and highway systems provide a critical role in creating and maintaining economic development and a desirable quality of life. Embedding environmentally sustainable principles and best practices into road projects in the developing world has been a challenge for governments and the International Financial Institutions. The problems faced in the developing world have many unique aspects including varying degrees of commitment, limited financial resources and lack of understanding about sustainability concepts and how to address them given the country specific characteristics.

The World Bank developed a guidance document to assist Bank project staff and its clients in integrating environmentally sustainable elements into road transportation projects, thus helping to promote green growth. The focus was to identify a range of ideas and options to improve environmental sustainability throughout all phases of the project cycle (system planning, project planning and design, construction and operation and maintenance) using a rating system tool. The approach builds upon five national and international sustainability rating systems and provides an extensive set of environmental road sustainability criteria. The guidance also presents a summary of road transportation environmentally sustainable technology information to stimulate consideration in existing and new road projects.

The paper presents a summary of contents and use of the sustainability-based road guidance and provides some case studies, insights and suggestions for moving forward given the initial findings from its use in Latin America.

© ASCE 2014

INTRODUCTION

In developing countries, reliable and safe road transport systems are integral for sustainable economic development, which assists in poverty reduction, shared prosperity and a desirable quality of life. Many transportation planners, engineers and environmental scientists worldwide recognize that roadway systems need to be more sustainable in light of finite natural resources, sensitive environmental conditions and limited economic resources. Sustainability is not just environmental considerations associated with energy conservation and alternative energy generation; it is the inseparable integration of the environmental, community/society and economic attributes that need to be managed at the project level to be effective and successful.

There can be important benefits associated with a sustainable road project including improved cost effectiveness, reduced material consumption, improved community quality of life, increased protection of finite environmental resources and improved consideration of a life cycle approach. Other potential related benefits can be enhanced innovation and increased knowledge transfer and capacity building. These, in turn, provide results to support an entity (e.g., transport agency) in terms of developing or demonstrating implementation of its sustainability goals and policy/programs. One approach to help promote environmentally sustainable transport projects has been an effort to develop comprehensive sustainability rating systems for transportation infrastructure systems (e.g., Envision, CEEQUAL, INVEST, Green Roads, GreenLITES, etc.).

However, embedding sustainability principles and best practices into road projects in the developing world has been a challenge due to many unique aspects including changing or varying degrees of commitment and limited financial resources. In addition, there is often a lack of understanding about sustainability concepts, how to address them given the country specific characteristics or the lack of availability of more sustainable based products and technologies in these countries.

The World Bank promotes a sustainability philosophy and vision for a "Green, Clean and Resilient World" and has been supporting various sustainable transport projects, such as more efficient rural road rehabilitation projects and clean mass transport systems. The World Bank Latin American and Caribbean Region undertook an effort to develop guidance to assist its clients and Bank project staff in better integrating environmentally sustainable elements into road transportation projects. The goal is to increase the inclusion of environmentally sustainable practices in developing country road transport projects and to improve local technical capacity and knowledge. The focus is to provide a wide range of potential ideas and options to improve the environmental sustainability throughout the road transportation project cycle (system planning, project planning and design, construction, operation and maintenance) based on indicators from a sustainability rating system tool and highlighting environmentally sustainable products and materials for road construction. The focus is on environmental related aspects within the broader concept of project sustainability. The Bank works to integrate these with other sustainability actions

© ASCE 2014

(e.g., financial/economic, social) in projects, as well as other areas such as governance and transparency.

The emphasis is on sustainable actions that go beyond compliance with applicable in-country environmental regulatory requirements (e.g., mitigation of negative impacts, compliance with environmental permits, etc.) and strive towards good/best practices such as the reduction of consumption (energy, water, materials, etc.), no net resource impact and social and environmental enhancement.

The objective of this paper is to summarize the concepts, content and use of the sustainability-based guidance and provide insights, lessons learned and suggestions for moving forward given the initial findings from its use in Latin America.

SUSTAINABILITY GUIDANCE

The sustainability guidance is separated into two parts:

- Potential ideas and options (presented as criteria or indicators) to improve the environmental sustainability throughout the road transportation project cycle and
- Potential environmentally sustainable products and materials for road construction.

Environmentally Sustainable Criteria

The sustainability criteria were created by first assessing existing sustainability guidelines and rating systems used for road transportation projects and conducting interviews with leading Latin American transportation professionals and professional societies. The guidance developed is a synthesis of sustainable best management practices criteria from principally five transportation and infrastructure sustainability rating systems:

- Envision (Institute for Sustainable Infrastructure),
- CEEQUAL (CEEQUAL Ltd., founded by the UK Institution of Civil Engineers),
- INVEST (United States Federal Highway Administration),
- Green Roads (Green Roads Foundation) and
- GreenLITES (New York State Department of Transportation).

The product consists of over 330 sustainability-based criteria separated into four main road transport project phases:

- 41 for Systems Planning,
- 108 for Project Planning and Design,
- 94 for Construction and
- 91 for Road Operation and Maintenance.

© ASCE 2014

These criteria are those that promote green infrastructure and strive toward resource enhancement and restoration. They do not include criteria associated with mitigation of negative impacts due to the road transportation construction and operations, which are included in all of the existing transport and infrastructure sustainability rating systems. Mitigation actions to address negative impacts are identified during project environmental assessments and permitting and thus such criteria are considered in the context of this guidance as obligatory and would be part of a project's environmental regulatory compliance.

However, it is possible that a negative impact mitigation measure can be done in a more sustainable manner. For example, it is possible that a storm water basin is required by a regulation during and after construction to contain storm water with high amounts of suspended and deposited sediment. The installation of the storm water basin is not considered a sustainability criteria/action in terms of this guidance. If a permanent wetland was constructed within or just downstream of the storm water basin, it can be used to treat and filter the storm water and it can also provide high quality habitat to wildlife, then this wetland creation is considered a sustainable action. Another example would be the use of more sustainable materials or approaches for erosion control and re-vegetation.

The criteria are presented in a tabular format for each project cycle/phase and have been grouped into categories and subcategories (see Table 1). The criteria tables include:

- Criteria - describes the sustainable criteria in a question based format that can be used to develop project specific sustainable actions.
- Indicator Measurement - identifies potential quantitative metrics or performance indicators for sustainability achievement as required by the cited references' rating system programs.
- Measuring Success - identifies potential ways to qualitatively measure and/or verify if criteria was selected and subsequently implemented on the project (note: not all criteria identified capability to have quantitative based performance measures).
- Key Indicator - generally prioritizes criteria based upon the level of resource enhancement and restoration, community quality improvement and economic cost effectiveness that should be considered for selection by the project team (note: key indicators are subjective in nature and may be dependent upon the project specific characteristics and contexts).
- References – source(s) of criteria (note: in some cases similar criteria from two or more references have been consolidated into one criterion).

Representative example criteria are presented in Table 2 for different project phases.

© ASCE 2014

Table 1. Categories and Subcategories of Environmentally Sustainable Criteria

Category	Sub-Category	Subcategory Elements and Definition
Quality of Life	Community Well-being	Improve community quality of life; stimulate growth and development; develop local skills and labor; improve mobility/access; encourage alternative transportation modes; enhance accessibility and safety
	Community Context	Plan and coordinate with community; design with sense of community; preserve views; enhance community public space; enhance cultural resources
	Economics	Facilitate movement of goods, services and freight; evaluate life cycle costs
	Safety and Health	Enhance public and worker health and safety; conduct accident and prevention studies; improve security
Project Leadership	Collaboration	Develop sustainability program; define team structure; monitor sustainability elements
	Management and Planning	Identify by-product synergies; implement training programs, long term monitoring and maintenance
Natural World	Siting-Alignment Selection	Preserve and enhance prime habitat, wetlands and surface water systems; preserve prime farmland; avoid adverse geology; enhance floodplains; avoid undeveloped land
	Land-Water-Wildlife Habitat	Manage pesticide/herbicide/fertilizer chemical usage; control surface and groundwater contamination; enhance wetland and surface water functions
	Biodiversity	Preserve and enhance species biodiversity, migration and mobility; manage invasive species
Natural Resource Management	Materials	Use recycled and reused materials; use or develop a sustainable procurement program; select road materials using local sources; use materials with cost effective longevity
	Recycling-Reuse	Divert waste from landfills; reduce materials taken from project site; plan project deconstruction and recycling
	Waste Management	Control hazardous and solid waste; develop waste minimization strategies
	Energy	Reduce energy consumption via renewable energy and energy conservation
	Water	Protect freshwater systems for domestic uses; implement water conservation; develop storm water management enhancement strategies
	Atmosphere	Manage noise/vibration, light pollution and air pollutant emissions
Climate Change	Resilience	Anticipate climate change induced threats; plan long-term adaptability; design for short term hazards and heat island effects
	Greenhouse Gas Emissions	Reduce greenhouse gas emissions

© ASCE 2014

Table 2. Representative Examples of Environmentally Sustainable Criteria for Different Project Phases.

Project Stage	Category	Sub-Category	Criteria	Indicator Measurement	Measuring Success	Key Indicator	Reference
System Planning	Quality of Life	Community Context	Does the transportation planning consider the unique and cultural characteristics of the communities by investing in healthy, culturally sound, safe and walk able neighborhoods?		Determine coordination with public officials and stakeholders; cultural information reviewed and summarized to identify unique community and cultural features; financial resources were estimated or obtained for enhancement	x	GreenLITES
Project Planning and Design	Natural World	Siting-Alignment Selection	Does the design conserve undeveloped land by locating alignments and right of ways on previously developed sites and/or previously contaminated sites?	Percentage of alignment area previously used: 25% 50% 75% 100%	Review design documentation to assess if alignment alternatives considered the placement in already developed or previously contaminated land; verify percentage of previously used area calculations	x	ENVISION
Construction	Natural Resource Manage-ment	Materials	Have existing structures, such as roads, tanks, pipe work, etc. been retained and used within the project?	Percent by volume:: <25% 25-50% 50-75% >75%	Review site photographs, construction drawings and bill of quantities coupled with substantiation of the percentage being claimed	x	CEEQUAL
Operation and Maintenance	Project Leadership	Management and Planning	Has the Agency or Operator done performance tracking by integrating quality and pavement performance		Ensure existence of a signed letter from the Agency or Operator stating that there is a performance tracking system in place, operational and populated with		Greenroads

			data using a process that allows quality measurements and long-term pavement performance measurements to be spatially located and correlated to one another?		the required data; obtain evidence in the field or in project file		

© ASCE 2014

Environmentally Sustainable Technology Information

An important element in improving the environmental sustainability of road transportation projects is the use of new technologies, processes and products that directly enhance the project environmental and economic sustainability through reduced energy and material consumption. The guidance provides information on some of the new sustainability-based technologies and approaches (e.g., innovative materials, energy conservation and generation, lighting, safety and wintertime maintenance operations) and a list of websites to stay current on new technologies, models and approaches.

Use of Guidance

The guidance is intended as "a tool" to aid road transport decision makers and technical specialists in striving for more environmentally sustainable road transport projects in developing countries. It is designed to be applicable at any project phase/stage, but ideally should be referred to early and routinely throughout the project process. It is not expected that a project will adopt all the criteria; instead, it should be used as a menu of "potentially sustainable ideas and options". The consideration should be done in a collaborative manner with relevant players (decision makers, road design engineers, environmental and social specialists, construction contractors and operation and maintenance specialists). The selection and success of selected sustainable actions will depend upon the local and environmental contexts of the project, the project size and scope and the overall project financial budget. Decision-maker and management support is also critical.

When selecting and integrating sustainable actions into projects, there needs to be a reasonable balance among environmental, social and economic elements. In some cases, it may be appropriate for a project team to focus more on the engineering aspects of the project such as material usage, waste reduction and recycling/reuse, while in others, more on community benefits or environmental enhancement. The selected sustainable actions need to be cost effective and provide added value to the project.

Measuring performance or success via field supervision, monitoring and documentation is an important step to demonstrate actual results and thus needs to be planned and implemented. Some criteria can be assigned quantitative performance metrics; however, the value needs to be weighed against the cost for data collection.

The guidance can be used as input or a reference to project design, construction and operation and maintenance contracts and also in third-party supervision contracts.

The guidance can also be useful in building technical capacity and institutional strengthening as a reference document.

© ASCE 2014

RESULTS AND MOVING FORWARD

The following presents a brief summary of a few case study examples in which environmental sustainability has been improved in World Bank financed road projects in Latin America.

Argentina. The project involved road paving of a 60 km section of Provincial Road 3 in the Northern Province of Chaco, Argentina. The road passes through a very vulnerable area of natural dry forest lands, identified as an extremely valuable corridor in the Gran Chaco region's biodiversity. As part of project design, this challenge was transferred into a sustainability opportunity by adopting a landscape approach to ensure works and environmental management measures would incorporate the functionality of the ecological corridor, supporting the conservation of the natural resources and helping to enhance knowledge and local cultural heritage. Examples of environmentally sustainable measures included awareness signs and speed reduction measures in critical habitat areas and key landscape connectivity points were established (eight underground and three canopy wildlife crossings). The work resulted in a scientific report on the ecological community in the area, based upon an expanded survey of plants and animals related to the project that went well beyond that needed for environmental impact analysis.

Brazil. The Tocantins Integrated Sustainable Regional Development Project includes various rural road improvements. The project promoted improved sustainability by, incorporating as part of the project planning and design stage, undertaking capacity building in areas of biodiversity protection, sustainable land use management, environmental monitoring strengthening and sustainable hydrologic resources management. It also supported establishment of an improved State environment policy and regulatory framework. The results included development of practices such as ecological corridors, integrated management strategies for water particularly in semi-desert areas, preparation of watershed master plans and orientations for basin committees, studies on land cover and fauna and flora and studies for 16 new protected areas.

Brazil. As part of the Mato Grosso do Sul State Road Transport Project, in one section of road MS-436, the original design planned a set of erosion control measures (materials, execution, etc.) costing approximately 1,080 million Reais (approximately USD 460 million). However, a cost reduction of ten percent was obtained by the project team during initial phases of construction by identifying and implementing more sustainable approaches, including utilizing an enhancing, natural vegetation recovery process with select re-vegetation techniques and using construction interventions that were more superficial (i.e., less depth).

The experience to date in attempting to improve environmental sustainability in Bank financed road projects in Latin America has demonstrated that:

© ASCE 2014

- The guidance has helped improve capacity among both Bank clients and staff but much more efforts are needed in this regard.
- Linking, and more importantly properly communicating, the benefits from implementing an environmentally sustainable action (criteria) requires focused attention and efforts.
- It is important to stress that while "ideally" addressing all the environmentally sustainable criteria maybe a goal, for projects in developing countries, that even the implementation of just one action that provides significant results can be deemed a success.
- It is never too late to implement environmentally sustainable actions, albeit the maximum benefits are likely obtained when implemented at the early project planning and design stage.
- Contrary to the belief of some, not all sustainability actions add to the overall project cost but the opposite, in that they may reduce material and energy consumption or other environmentally related project costs.

Based upon the experience, the following are some suggestions or opportunities for moving forward:

- Develop and implement specific training/learning events that focus on demonstrating the value (benefit) for decision-makers and the range of potential environmentally sustainable actions for technical specialists.
- Improve the identification (and quantification to extent possible) of benefits from implementing environmentally sustainable actions in developing country road projects, including case study examples.
- Develop more specific and detailed approaches for incorporation in project contracts (design, construction, operation and maintenance and construction supervision). Approaches should especially consider proactive actions by relevant players and rewarding positive results.
- Improve the identification of "high return" environmentally sustainable actions, in the context of developing countries and their intrinsic characteristics, thus assisting in prioritization of actions to implement first.
- Develop better cost-benefit approaches for monitoring/supervision of implementation of environmentally sustainable criteria, in light of cost and resource limitations in most developing country road projects.
- Expand the environmental sustainability criteria to provide more quantitative levels and allow for numerical calculation of sustainability.

REFERENCES

Bogota Declaration; Sustainable Transport Objective; Foro de Transporte Sostenible para America Latina; First Regional Forum on Sustainable Transport (FTS), June 24, 2011

© ASCE 2014

CEEQUAL, The Assessment and Awards Schemes for Improving Sustainability in Civil Engineering and the Public Realm; Scheme Description and Assessment Handbook; Version 4.1, August, 2010

Compendium of Sustainable Development Indicator Initiatives; http://www.iisd.org/measure/compendium/, July, 2012

ENVISION Version 2.0; Stage 2 Checklist; Institute of Sustainable Infrastructure; Zofnass Program for Sustainable Infrastructure (Harvard University), 2011

ENVISION Stage 1 Second Draft; Institute of Sustainable Infrastructure; Zofnass Program for Sustainable Infrastructure (Harvard University), 2011

Greenroads; Greenroads Abridged Manual; Version V1.5; Abridged version (updated), February 4, 2011

GreenLITES Operations; New York State Department of Transportation; GreenLITES Operations Certification Program Draft, 2009

GreenLITES; New York State Department of Transportation GreenLITES Project Design Certification Program; Recognizing Leadership in Transportation and Environmental Sustainability; Revised December, 2009

INVEST Federal Highway Administration Compendium of System Planning and Processes; Project Delivery and Operations & Maintenance Criteria (Pilot Version), October, 2011

International Road Federation Innovative Practices for Greener Roads; http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf, 2009

World Bank Transport Business Strategy 2008-2012; Safe, Clean, and Affordable Transport for Development; The World Bank Group's Transport Business Strategy 2008-2012, World Bank 2008

World Bank Environment Strategy 2012-2022; http://siteresources.worldbank.org/ENVIRONMENT/Resources/Chapter_1_WBG_Environment_Strategy.pdf , 2012

© ASCE 2014

Sustainability Quantification System: A quantitative approach to evaluate transportation sustainability in U.S.

Hariharan Naganathan[1], Wai Kiong Chong[2], Steven D. Schrock[3]

[1] Graduate student, School of sustainable engineering and built environment, Arizona State University. Email: mail4hariharan@gmail.com
[2] Associate Professor, Del E. Webb School of Construction, Arizona State University. Email: ochong@asu.edu
[3] Associate Professor, Civil, Environmental and Architectural engineering, University of Kansas. Email: schrock@ku.edu

ABSTRACT

Sustainable practices have become the cornerstone of the transportation sector, and widely adopted by many states' transportation agencies. Sustainable practices have now become the edifice of the transportation sectors but the adoption of such practices is not fast enough to overcome the ever-increasing global demand for resources. There are numerous sustainable policies, rating systems, and most of them follow similar approaches and formats that outline the sustainability factors. This paper proposes a quantitative approach to measure and evaluate sustainable performance of the transportation sector. The paper makes an extensive analysis on carbon emissions when treated by total population and Gross Domestic Product (GDP). The evaluation focuses on the transparency of sustainability through measurement and quantification of sustainability rather than to develop standard compliance approaches. These measurement and quantification approaches would allow transportation agencies to measure and thus reduce their footprints.

BACKGROUND

The scope of sustainable transportation is emerging into reality as a part of broader scheme of transportation. It is emerging as an epitome of global sustainability growth and aims at integrating resource conservation through transportation. Transportation influences all aspects of the economy, environment and society and generates long-term impacts on humanity (Dearing, 2000). Sustainability in transportation addresses the basic needs of societies such as safety and in a manner consistent with the health of human and ecosystem through transportation infrastructure. Sustainable transportation indicators are critical to measure the sustainability of transportation policies and practices.

Amekudzi (2005) presented the sustainable transportation frameworks through thorough literature search, and placed the indicators into three categories: linkages-based, impact based and influence oriented. Litman (2006) included indicators that are separated into economic, social and environmental categories. Gudmundsson (2000) developed an understanding on how transportation planning is adopted in the U.S. and Canada and identified the indicators used to benchmark sustainable transportation performances. Segnestam (1999) examined the

© ASCE 2014

environmental performance indicators (EPI) which is required to monitor and evaluate environmental problems. Gilbert & Tanguay (2000) examined and listed the sustainable indicators used globally to evaluate sustainable transportation. The works by Segnestam (1999), Gilbert & Tanguay (2000), Litman (2011), Adjo (2005), Gudmundsson (2000), Meyers (2000), Cortese (2003), and Wheeler (2003) identified the indicators for transportation sustainability, and thus laid the foundation for the development of sustainability quantification for the transportations sector.

The research team also conducted reviews on various non-transportation and transportation sustainability rating systems to understand how both transportation and non-transportation sectors quantify and implement sustainability. The reviews showed that there are over 200 sustainable rating systems globally. Each rating system targeted specific markets, regions and products. Some of these rating systems include the United States Green Building Council's Leadership in Energy and Environmental Design, and the Institute of Sustainable Infrastructure's Envision. These rating systems use the compliance strategy to differentiate "sustainable" and "non-sustainable" systems, and do not quantify the actual sustainability impacts. The weights and evaluation processes are the important goals of these rating systems and they are extremely useful to their particular industries to define what is/are "sustainable" and what is/are not.

RESEARCH NEEDS AND OBJECTIVES

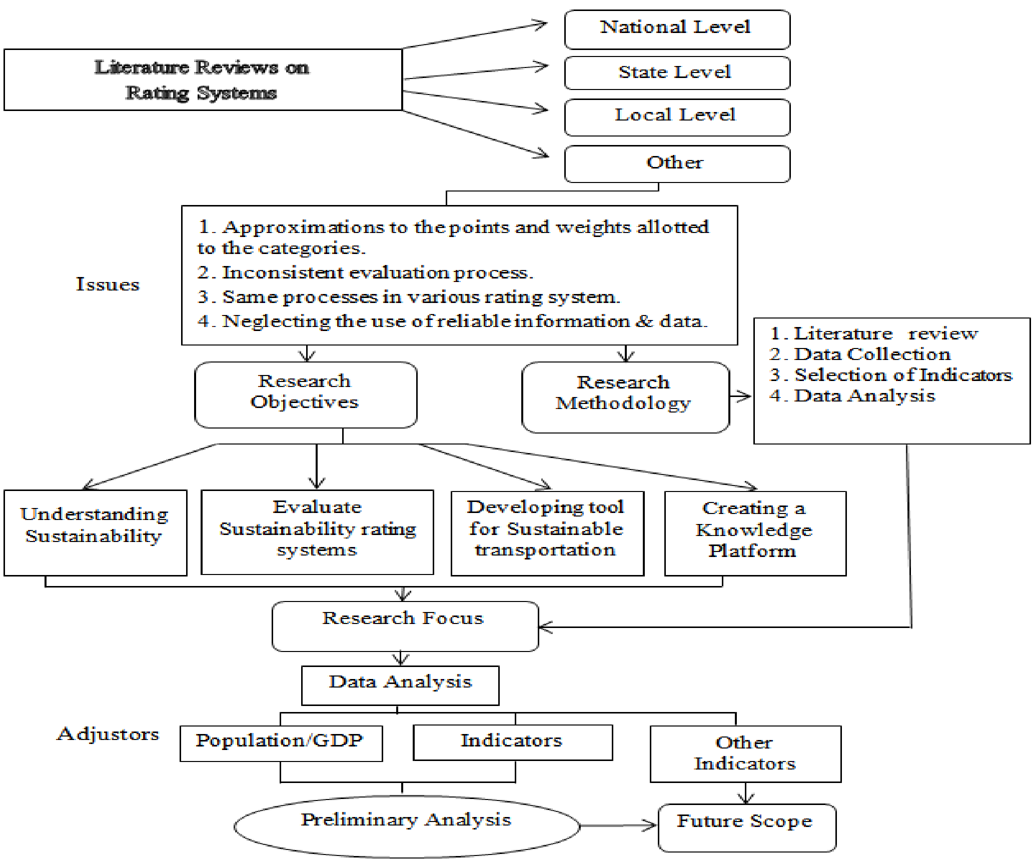


Figure 1. Flow chart representing Research Focus and outcomes

© ASCE 2014

The literature search highlighted that there is no existing quantification methods for sustainability. The "compliance" versus "non-compliance" approach is the most commonly used method to determine the sustainability of systems. As mentioned above, many literatures have indicated the needs to establish sustainability indicators and the need to quantify them. Literature review indicates that there are only a handful of quantification approaches. In short, there is a need to develop a method to determine what and how much a sustainable system has achieved. At this time, the users can only determine if they have complied with a system or not. In addition, it is important to understand what compliance actually means. That being said, it is extremely difficult to develop the quantification methods for sustainability due to the lack of data, and models have to be developed to address such scenarios. The purpose of this research is to advance the science of sustainable engineering by developing the quantification method for sustainability using the indicators identified from existing literature. Figure 1 highlights the framework of this research. Due to the limitations of pages, the foci of this paper are on the states' transportation sustainability, their carbon emissions, and energy use. The indicators are based on the findings from Segnestam (1999), Gilbert & Tanguay (2000), Litman (2011), Adjo (2005), Gudmundsson (2000), Meyers (2000), Cortese (2003), and Wheeler (2003).

RESEARCH METHODOLOGY

A significant part of this research is dedicated towards the data collection and analyses for the development of the analysis framework that will be used to benchmark and quantify the sustainability of states and their transportation agencies. The information came from several sources: (1) The databases and documents published by various US public agencies, like the United States Department of Transportation (USDOT), Energy Information Administration (EIA), Environmental Protection Agency (EPA), American Public Transportation Association (APTA) and American Public Works Association (APWA). Documents and articles published by state DOTs are also used as information for the project; and information was also collected directly from various DOTs.

DATA EVALUATIONS

A data analysis framework is developed to lay out the relationships between the data, and their intended output. The data are grouped by Budget, Ridership, Emissions, Consumptions and Energy Efficiency (BRECE). BRECE are indicators on the dedications and achievements on various sustainability efforts implemented by the transportation sectors. The selection of these indicators is based on: (1) reliability of information; (2) data availability; and (3) the importance of the indicators. The organization of the analyses will follow similar approaches adopted by the National Institute of Standards and Technology (NIST), American Society of Civil Engineers (ASCE), Institute for Sustainable Infrastructure (ISI), and Federal Highway Administration (FHWA).

The analyses generate output that allows states to compete and learn from one another so that they can improve their transportation sustainability performance. The research team focuses on the analyses of several critical indicators that are grouped under BRECE. Due to the page restrictions, this paper makes an extensive analysis only on carbon emissions. The adjustors used in this research are population and gross domestic products (GDP). The population and GDP are used as the two "adjustable" variables for the different set of indicators.

CARBON EMISSIONS AND POPULATION

The carbon footprints of transportation agencies should be included in the indicator since they generate and use huge amounts of energy and emit significant amounts of carbon. Since carbon emission is an important indicator for the research, the emission data from the transportation sector of each state is collected from state DOT websites and from the Energy Information Administration (EIA).

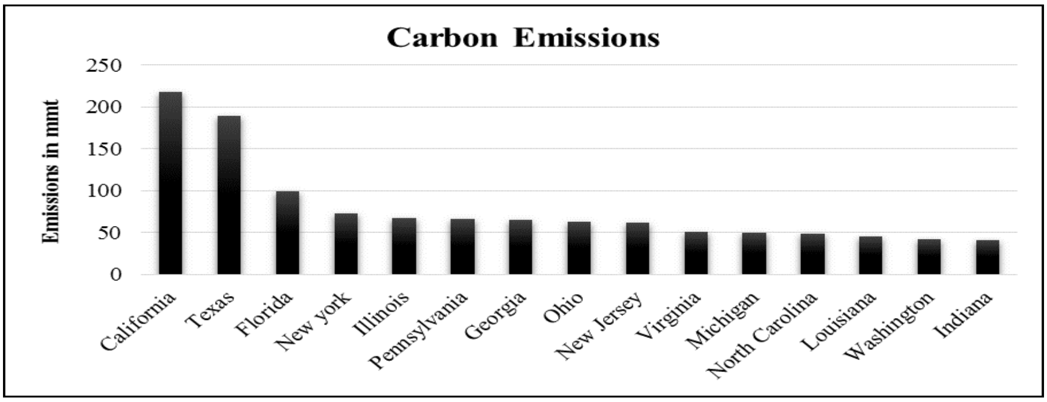


Figure 2. Top 15 states on Carbon emissions (EIA, 2010)

Figure 2 shows that California, Texas and Florida are the top three states contributing to transportation carbon emissions. Figure 4 shows the list of top states after adjusting by the population. Alaska stands top among the states followed by Wyoming and Louisiana. Bigger states like Texas fall lower on the table after this adjustment.

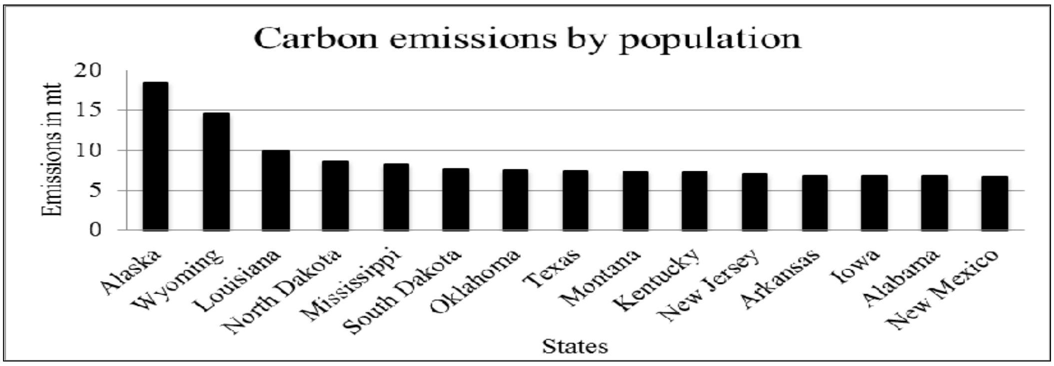


Figure 3. Ranking on emissions per capita (metric tons) (EIA, 2010)

Analysis: Larger states like California and Florida are outranked when carbon emission is adjusted by their population; smaller states like Wyoming and Alaska topped the carbon emissions per capita ranking. Does this mean the more densely populated states have low emission per capita than the less densely populated states? It is difficult to conclude as the analysis identifies the impacts of population as an

© ASCE 2014

adjustor of the carbon emissions due to transportation. Alaska has a smaller population and thus larger transportation budget per capita. Transportation development moves at a slower pace because of climate conditions resulting in greater reliance on private transportation than public transportation, which may be the reason for the greater carbon emissions.

CARBON EMISSIONS AND GDP

The elevation in renewable energy production and other sustainable initiatives doesn't contribute completely to the ever growing demand. GDP of a state may have a positive correlation with the energy use of the state. Energy use increases with material manufacturing and other which in turn increases emissions. Thus, the GDP of the state is directly related to the carbon emissions. So does this mean California, the state with the largest GDP, has higher emissions than other states? There is a requirement of in-depth data analysis as it is vague to conclude as such. GDP plays with real data and returns results that are more reliable on sustainability ranking when used as an adjustor. When carbon emission is adjusted, Minnesota and Alaska rank at the top of the table whereas major states like California and Texas drop down.

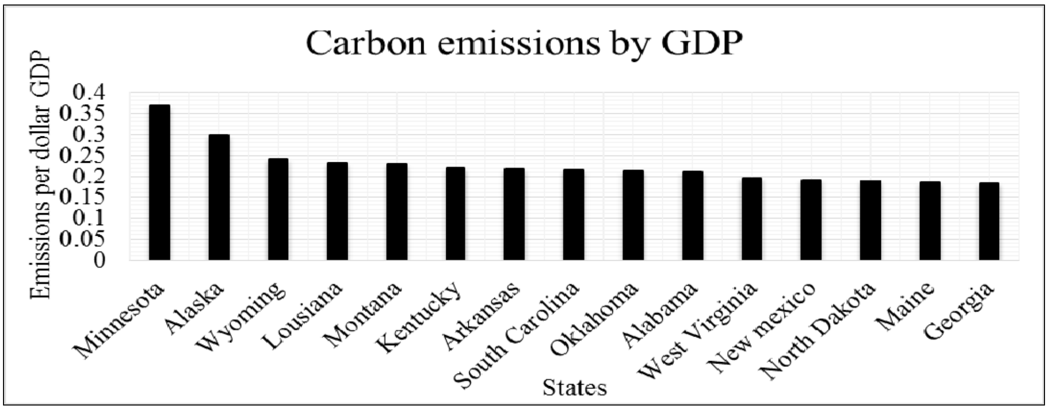


Figure 4. Carbon emissions per dollar GDP (EIA, 2010)

From the analysis, with adjustment through GDP on emissions and consumption, Minnesota stands first in all three analyses. This can infer that Minnesota has a larger impact on sustainability through GDP. The carbon emission of Minnesota is relatively high to its GDP (from the data collected). This can be a reason for Minnesota to be on the top of the list. Also, Minnesota is an industrialized state which has the headquarters of major public companies (Target, Hormel Foods, and BestBuy). This can also be a reason for greater consumption and emission rates. It is also one of the largest producers of sweet corn and hence fuel can be utilized in food production and other product manufacturing (Department of Employment, 2006).

ENERGY CONSUMPTION AND POPULATION

The EIA estimated that transportation consumed 29 percent and transportation-related construction and infrastructure consume another 10 percent of all energy used in the United States (EIA, 2010). While rail transport is the most energy-efficient mode of land transportation (Rodridge, 2013), private automobiles have the capability to transport huge numbers of passengers due to low-density residential population. Transportation accounts for approximately 25 percent of world energy demand and for more than 62 percent of all the oil used each year (World Energy Council, 2007).

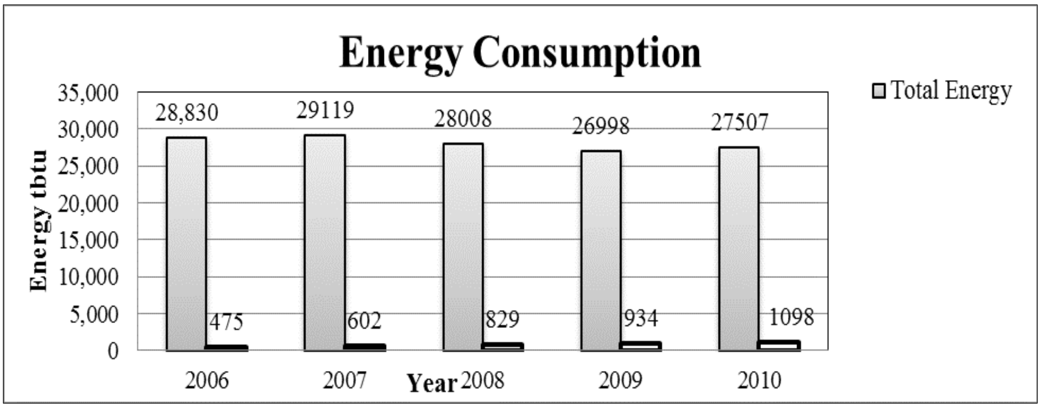


Figure 5. Details on energy consumption by Transportation sector (EIA, 2010)

Figure 5 illustrates that there was marginal change in energy consumption from the year 2006 to 2010 by the transportation sector. The total amount of energy consumed in 2007 was greater than it was in 2010, and the lowest of the 5 years was the year 2009. The figure also shows renewable energy production in the country. However, the margin is low compared to the overall energy consumption. Renewable energy use increased steadily over the year. This shows that the production and consumption of renewable energy have increased over years but much more is still required to balance the amount of fossil fuel utilization.

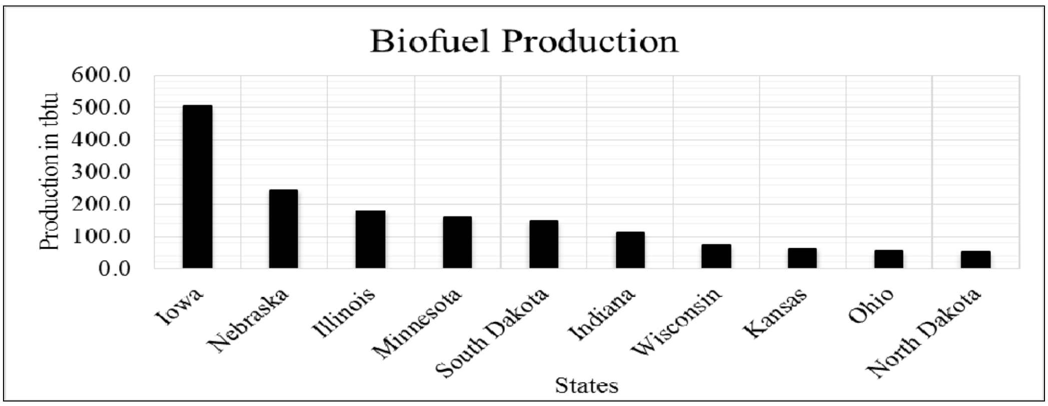


Figure 6. Biofuel production (Trillion Btu); Source: (EIA, 2010)

Figure 6 shows the biofuel production in various states. Biofuel production is considered for analysis to determine the amount of biofuel energy used in the transportation industry and how it affects sustainability. Biofuel includes both biodiesel and fuel ethanol. Figure 6 shows Iowa tops the list on biofuel production followed by Nebraska and Illinois. Small states like Kansas and North Dakota produce a significant amount of biofuel.

Analysis: The production of biofuel in a state may suggest that the use of fossil fuels can be reduced. Biofuel has the potential to replace fossil fuel to run transports in the country. Most biofuel comes from ethanol produced from corn. Iowa, Nebraska and Illinois are three of the top corn producing states traditionally. Thus, their ethanol production level comes as no surprise. The sustainability of these states can be measured in two ways, first, its biofuel production and second, the use of biofuel by the local transports.

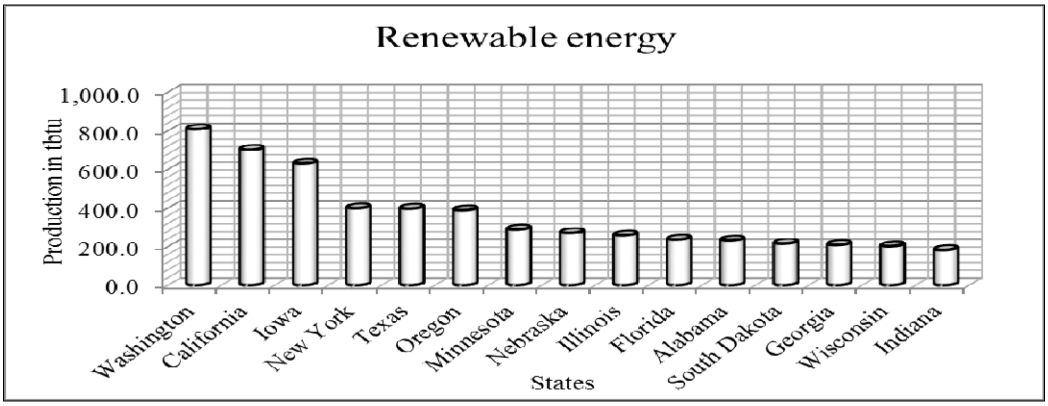


Figure 7. Renewable energy production (EIA, 2010)

Figure 7 shows renewable energy produced in each state and their biofuel production. As shown in figure 6, Iowa and Nebraska are top producers of biofuel. Figure 7 shows Washington produces more renewable energy than any other state whereas California is second. Iowa stands third and better than New York and Texas. Nebraska concentrates on biofuel production whereas New York and Texas, more densely-populated states have lower biofuel production.

Inference: The United States generates the highest energy footprint per capita in the world. In the near future, renewable liquid fuels like biodiesel and ethanol are the only viable options to replace fossil fuel if vehicles continue to use liquid fuels rather than electricity. The scenario will be different if electric vehicles become more prominent. Thus, the use and production of ethanol and biodiesel are extremely important in the United States. The reduction of fossil fuel use also reduces pollution, carbon emissions and overall energy use. Motor gasoline is the highest consumed fuel in the United States (EIA, 2010), by both government and private sectors. Though there are numerous efforts to promote the use of renewable energy and manufacture alternatively-fueled vehicles, these efforts and their effects take time to realize. Travel distances between work, home, and play became longer, increasing the dependence on fossil fuels in the United States since the long distance travel for

© ASCE 2014

day to day activities primarily utilizes private transportation. Many public transportation options are expensive to maintain due to the cost of operation and low ridership. Low density development makes public transit less viable in many regions.

CONCLUSION

Sustainability plays an important role in the transportation infrastructure. It aims at formulating policies and techniques in order to achieve optimization of resource utilization so that it will not be depleted in the near future. The research team conducted an extensive literature review on various rating systems and also to understand prior research initiatives on sustainable transportation.

Also, the indicators (BRECE) are adjusted through population and GDP which are considered to be the root cause for several outcomes of the economy, society and environment. The GDP per capita generally determines the economic growth of a country. The research team worked on a different dimension adjusting emissions, registered automobiles and energy consumption through GDP. The GDP and the wealth of people are considered to be inversely proportional to each other. When a citizen decides to use public transit and reduce self-transportation, the GDP goes down because of low flow of money (purchase of automobiles). Table 1 lists the ranking of states based on carbon emission by population and GDP, bio fuel production and renewable energy utilization. The paper did not include all the indicators used in this research due to page restrictions.

Table 1. Ranking of states

Sustainable Indicators	Top 3 States			Bottom 3 States			Indicators used
Carbon emissions	CA	TX	FL	DC	VT	RI	1.Carbon emissions 2.Population 3.GDP
Carbon emission per capita	AK	WY	LA	DC	NY	RI	
Carbon emissions/GDP	MN	AK	WY	DC	NY	CT	
Renewable Energy	WA	CA	IO	DC	RD	DE	Renewable energy use
Biofuel production	IO	NE	IL	WV	WA	VA	Biofuel production

The focus of this research is to quantify the sustainable performances through real datasets which is collected from the reliable sources. This will help the transportation industry (state agencies) to instigate and understand their real sustainable target which gives more transparent outcomes rather than relying on their traditional rating systems. The purpose of this paper is to propose a quantification methodology and approach which can be used by the transportation agencies irrespective of their transportation policies and requirement standards. Also, the research team aims at creating a web based platform disseminating this information. The future directions of this research include the addition of more indicators,

© ASCE 2014

including various other modes of transportation (freight and shipping), and to provide a web-based platform which will be focused as one solution for transportation sustainability.

ACKNOWLEDGEMENT

The research team would like to thank the Transportation Research Institute (TRI) and various DOTs personnel for providing the funding, information and support for this research.

REFERENCES

Adjo Amekudzi, C. M. (2005, March 1). Addressing Sustainability in Transportation Systems: Definitons, Indicators and Metrics. *Journal of Infrastructure system, 11*(Sustainability Of Transportation And Other Infrastructure Systems), Pgs. 31-50. doi:10.1061/ASCE1076-0342(2005)11:1(31)

Daniel and Litman. (2011). *Sustainable Transport Evaluation*. Natural Conservation and Nuclear safety, Ministry of Environment. Eschborn: Federal Ministry of Environment. Retrieved March 3, 2014, from http://www.un.org/esa/dsd/resources/res_pdfs/csd-19/Background%20Paper%2010%20-%20transport.pdf

Dearing. (2000, November). Technologies supportive of sustainable transportation. (A. Gadgil, Ed.) *Environment and resources, Vol.25*, Pgs. 89-113. doi:10.1146/annurev.energy.25.1.89

Deodhar, D. a. (2013). Lean Six Sigma Principal In Construction:A Literature Review Related To Abstract. *Journal Of Information, Knowledge And Research In Civil Engineering, Vol.2,Issue* 2, Pgs. 133-139. Retrieved from http://www.ejournal.aessangli.in/ASEEJournals/CIVIL25.pdf#page=1&zoom=auto,0,849

Department of Employment. (2006, December 13). *Wealth of resources*. Retrieved 09 13, 2013, from Minnesota: http://www.positivelyminnesota.com/Business/Locating_in_Minnesota/Why_Minnesota/index.aspx

Dondero, George. (2012, November 15). *Developing a Comprehensive Sustainable Analysis Framework*. Retrieved May 15, 2013, from SCCRTC: http://sccrtc.org/wp-content/uploads/2010/12/TRB-STARS-Paper-121115-GD-revision.-Final.pdf

EIA. (2010, May 10). *Annual Energy Review: Total Energy*. Retrieved May 10, 2012, from U.S. Energy Information Administration: http://205.254.135.24/totalenergy/data/annual/pdf/sec2_5.pdf

EIA. (2010, December 8). *EIA*. Retrieved May 18, 2013, from U.S Energy information Administration: http://www.eia.gov/oiaf/1605/ggrpt/carbon.html#transportation

© ASCE 2014

EIA. (2010, June 12). *EIA*. Retrieved May 12, 2013, from Total energy Data: http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0201e

EIA. (2010, April 12). *Energy Efficient of the Transportation Sector*. (Energy Information Agency) Retrieved May 12, 2012, from The Transportation Sector - Chapter 5: http://www.eia.gov/emeu/efficiency/ee_ch5.htm

EPA. (2012, April 12). Environmental Protection Agency: Climate Change - Greenhouse Gas Emissions. Washington, District of Columbia, USA: Environmental Protection Agency. Retrieved May 2012, from 2012 U.S. Greenhouse Gas Inventory Report: http://www.epa.gov/climatechange/emissions/downloads12/US-GHG-Inventory-2012-ES.pdf

Gilbert and Tanguay. (2000). *Brief review on some relevant world wide activity and development of an initial long list of indicators*. Environment Canada, Government of Canada. Ontorio: Transport Canada. Retrieved Feb 2018, 2014, from http://cst.uwinnipeg.ca/documents/STPI%20Phase%201%20report.PDF

Gudmundsson H. (2001, June 12). *Indicators and performance measures for transportation, Environment and Sustainability in North America*. National Environmental Research Institute. Denmark: National Environmental Research Institute. Retrieved from Department of Policy analysis: http://www2.dmu.dk/1_viden/2_publikationer/3_arbrapporter/rapporter/ar148.pdf

Kimberly Amadeo. (2013, August 10). *US Economy*. Retrieved September 6, 2013, from About.com: http://useconomy.about.com/od/grossdomesticproduct/p/GDP.htm

Litman. (2006). Issues in sustainable Transportation. (D. M. Dorgham, Ed.) *Internation journal of Global environmental issues,Vol. 6*, Issue 4, Pgs. 331-347. doi:10.1504/IJGENVI.2006.010889

Litman, T. (2012, September 10). *Evalauating Transportation land use impacts*. Retrieved from Victoria transportation policy institute: http://www.vtpi.org/landuse.pdf

Liu, L. (2010). *Tracking The Life Cycle Of Construction Steel: Developing A Resource Loop*. University of Kansas, Civil, environmental and architectural engineering. Lawrence: KUSCHOLARWORKS. Retrieved October 16, 2013, from https://kuscholarworks.ku.edu/dspace/bitstream/1808/5707/1/LIU_ku_0099M_10658_DATA_1.pdf?origin=publication_detail

Rodridgue, J.-P. (2013). Transportation and Energy. In J.-P. Rodrigue, *The geography of transportation systems* (3rd ed., p. 416). New York, New York, United States: Department of Global studied and Geography. Retrieved

© ASCE 2014

August 20, 2013, from The Geography of Tranportation: http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c2en.html

Segnestam, L. (1999). *Environmental Performances Indicator*. Environmental Department. Washington DC: Environment department: The World Bank. Retrieved February 18, 2014, from http://www-wds.worldbank.org/servlet/WDSContentServer/IW3P/IB/2000/02/09/000094946_00012505400754/Rendered/PDF/multi_page.pdf

© ASCE 2014

Linking Disaster Resilience and Sustainability

Tonatiuh Rodriguez-Nikl[1], Matthew Comber[2], Simon Foo[3], Sally J. Gimbert Carter[4], Lionel Lemay[5], Panagiotis Koklanos[6], Lindsey Maclise[7], Martha G. VanGeem[8], and Mark D. Webster[9]

[1] Assistant Professor, California State University, Los Angeles, 5151 State University Drive, Los Angeles, CA 90032, Phone: (323)343-4456, Email: trodrig7@calstatela.edu
[2] Structural Engineering Manager, Project Frog, San Francisco, CA
[3] Public Works & Government Services Canada, Gatineau, Quebec
[4] Structural Engineering Design Professional, HOK, New York, NY
[5] Sr. Vice President, Sustainability, National Ready Mixed Concrete Association
[6] McLaren Engineering Group, West Nyack, NY
[7] Forell/Elsesser Engineers, San Francisco, CA
[8] Consulting Engineer, Mount Prospect, IL
[9] Simpson Gumpertz & Heger Inc, Waltham, MA

ABSTRACT

Structural engineers often limit their involvement in sustainability to material selection and recycling. Few structural engineers recognize the relationship between sustainability and disaster resilience. In response, the Sustainability Committee of the Structural Engineering Institute wrote a committee report to raise awareness of and provide guidance on the pertinent issues. This paper highlights the salient parts of the committee report. The introduction explains the relationship between sustainability and resilience and reviews the impacts of natural disasters. The following sections discuss general consideration for resilient design and summarize efforts to promote resilience and guidance for resilient design. Next are discussed current efforts to quantify the connection between disaster resilience and sustainability. The paper concludes with suggestions for structural engineers who are interested in supporting disaster resilience and sustainability.

INTRODUCTION

The importance of sustainability within structural engineering has become more widely accepted during the last decade. Structural engineers most often think of sustainability as pertaining to material selection and recycling. Many professionals also consider issues such as durability, obsolescence, and the impact of structure on operational efficiency. While the link between disaster resilience and sustainability has been recognized already (e.g., FEMA, 2000; NIBS, 2012), the structural engineering community has not yet embraced this relationship (some notable exceptions are Kneer and Maclise, 2008; Bocchini et al., 2013). In light of this, the Sustainability Committee of the Structural Engineering Institute wrote a committee report (Rodriguez-Nikl et al., in press) with the following aims:

- Raise awareness of the relationship between disaster resilience and sustainability by discussing how a holistic view of sustainability must recognize the need for disaster resilience, and
- Provide a critical review of resilience-related efforts and resources available to practicing structural engineers and related professionals

© ASCE 2014

This paper summarizes the salient findings of the committee report.

SUSTAINABILITY

In-depth discussions on sustainability and resilience are beyond the scope of this paper; they are discussed here briefly for background. Within the civil engineering profession, two definitions are commonly offered for sustainability. These are the Brundtland Definition which is stated as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987) and the Triple Bottom Line, which views sustainability as satisfying three objectives: not only economic but social and environmental as well (Elkington, 2004). This is also sometimes referred to as "People-Planet-Profit" or the "Three Pillars of Sustainability". To date, most efforts to promote sustainability have resulted in green certifications, codes and standards, whose focus is primarily on the direct impacts of the project on its surrounding environment. (As used here, "green" refers to efforts to reduce environmental impacts in some way. It is not used as a carefully defined technical term.) LEED (Leadership in Energy and Environmental Design; LEED, 2014) is the best known of the currently available sustainability rating systems for buildings. The Institute for Sustainable Infrastructure has released Envision, a similar rating system for infrastructure (ISI, 2014). These rating systems have different but similar sets of criteria that encourage the designer to consider issues such as site selection, energy efficiency (buildings), material use, water use and pollution, indoor environmental air quality (buildings), and quality of life. Envision provides five credits related to resilience.

The focus of the structural engineer within the context of these rating systems is usually limited to reduction of the embodied impacts of construction materials. Some building designers also consider the effect of the structure on the operational performance. These important considerations are discussed by Kestner et al. (2010). Less often considered but no less important is functional resilience, which is defined here as the ability of a facility to continue to serve its function by avoiding (a) deterioration due to environmental attack, (b) obsolescence due to changes in usage, and (c) damage due to natural or man-made disasters. Each component of functional resilience merits in-depth consideration. Kestner et al. address durability (related to environmental exposure) and design for adaptability and deconstruction (related to obsolescence and changes in usage). Disaster resilience receives much less attention in the sustainability literature.

DISASTER RESILIENCE

Various organizations and individuals define disaster resilience differently (e.g., NAS, 2012; NIAC, 2009; PPD, 2013). Bocchini et al. (2013) concluded there are two constants in most definitions of resilience: "(i) resistance to an unusual external shock (often referred to as 'robustness') and (ii) ability to recover quickly (often called 'rapidity')". Important aspects of resilience can be seen in the resilience triangle first proposed by Bruneau et al. (2003) and adapted in Figure 1. This figure represents the "quality of infrastructure", where 100 is the pre-disaster level. A disaster occurs at time t_o, causing an immediate loss of quality from 100 to Q_o. Mitigation efforts try to increase robustness to reduce the magnitude of this loss. After the event, recovery efforts aim to restore (or even improve) pre-disaster quality. The time at which this is accomplished is at time t_f. The ratio of the area under the curve to the total area between t_o and t_f can be viewed as a metric of resilience. The structural engineer's main contribution is to mitigation (limiting the losses at t_o). Through intelligent design – e.g., designing easily repairable structural elements

© ASCE 2014

such as fuses in seismic force resisting systems – the structural engineer can also contribute to recovery efforts (reducing time to t_f).

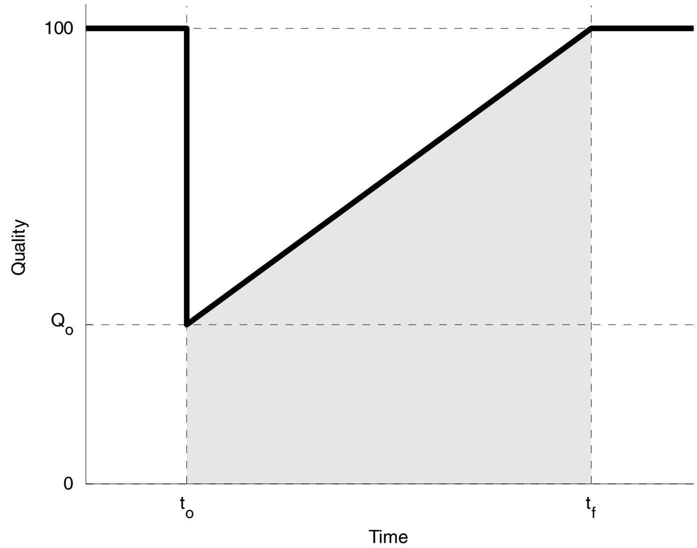


Figure 1: Resilience Triangle (adapted from Bruneau et al., 2003)

RELATION BETWEEN DISASTER RESILIENCE AND OTHER ASPECTS OF SUSTAINABILITY

Sustainability is a complex concept that touches on many aspects of the built environment. Resilience is just one consideration to achieve sustainability; many other traditional design considerations are also necessary (e.g., those presented by Kestner et al., 2010). The range of different requirements can present a difficulty when resilience and other aspects of sustainability are not compatible. This can occur, for example, in the following cases.

- A recycled material may not be as reliable as a traditional material
- An innovative design may not be as reliable as a traditional design
- A design that strives for minimum material use may be less redundant
- The added weight of a green roof may be detrimental to the seismic performance of a building

Many other connections between traditional sustainable design and disaster resilience should be explored. The structural engineer and the design team must bear in mind the concepts summarized in Figure 2. Traditional sustainable design and disaster resilience can both influence each other in both positive and negative ways. Such considerations greatly increase the complexity of a design project.

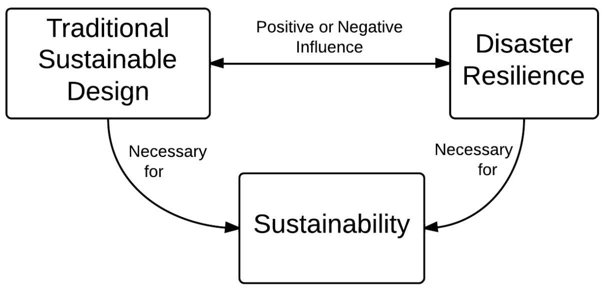


Figure 2: Relation between traditional sustainable design, disaster resilience, and sustainability

THE IMPORTANCE OF RESPONDING TO NATURAL DISASTERS

In 2011, the U.S. experienced 14 separate disasters, each with an economic loss of $1 billion or more, totaling $55 billion and surpassing the record set in 2008 (NOAA, 2012). Insurers lost at least $108 billion on disasters globally in 2011, the second-worst year in the industry's history. Only 2005, with Hurricane Katrina and other major storms, was more costly (AFP, 2011). In 2012, there were 11 natural disasters, each costing $1 billion or more in damage, making 2012 the second highest year with billion-dollar disasters. Figure 3 shows the number of hurricanes in

© ASCE 2014

each decade and the corresponding increase in losses (similar trends exist for other types of disasters). The increase in losses can be primarily attributed to population migration and increase in wealth. In the last several decades, population in the United States has migrated toward the coasts, concentrating along the earthquake-prone Pacific coast and the hurricane-prone Atlantic and Gulf coasts (CRS, 1997). In addition, the economic value of possessions has increased substantially. While the high concentration of people in coastal regions has produced many economic benefits, this has also increased the consequences of natural hazards. Moreover, many elements of the aging infrastructure in these areas are highly vulnerable to breakdowns that can be triggered by relatively minor events.

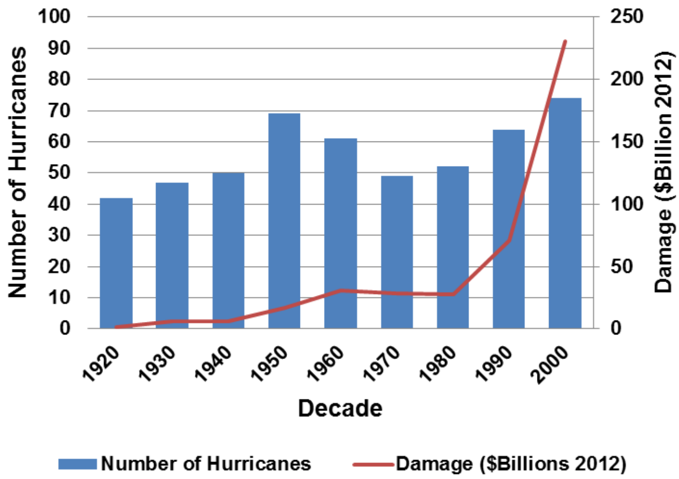


Figure 3: Number of hurricanes and damage by decade (wunderground, 2013)

Climate change is also implicated in the rise in storm-related losses. The National Academy of Sciences (NAS, 2012) states, "Impacts of climate change and degradation of natural defenses such as coastal wetlands make the nation more vulnerable." Larsen et al. (2011), writing on green buildings and climate resistance, conclude that climate change is already increasing storm intensity, raising sea levels, and accelerating coastal erosion, among other effects. They state, "The effects of climate change will likely be more extreme than what we have observed so far. With each additional increase in the global mean annual temperature, the severity of the effects is likely to worsen".

Despite the increased risk, there is strong evidence that hazard mitigation can be implemented successfully and with significant benefit. The Multihazard Mitigation Council (MMC) of the National Institute of Building Sciences conducted an independent study on the effectiveness of government sponsored disaster mitigation activities (MMC, 2005). The study indicated that the natural hazard mitigation grant programs funded by the Federal Emergency Management Agency (FEMA) were cost-effective and reduced future losses from earthquakes, wind, and floods; every dollar spent on hazard mitigation provided four dollars in future benefits.

GENERAL CONSIDERATIONS FOR RESILIENT DESIGN

There are various strategies available for achieving resilient designs, ranging from prescriptive approaches to detailed analyses that include probabilistic assessments of the hazard and the resulting damage. The simplest approach is prescriptive. In a prescriptive approach, rules specify what the engineer must achieve and avoid in the design. These rules are similar to traditional code regulations, but with stricter requirements. For example, the rules may state an increased design load or additional detailing requirements. Prescriptive guidelines are built upon many assumptions about the nature of the hazard, the structural response, and the design objectives.

© ASCE 2014

When using a prescriptive approach, the design professional must evaluate these assumptions against the objectives of the project. If the two are not consistent, a more detailed analysis should be conducted.

Kneer and Maclise (2008) highlight the importance of thinking beyond prescriptive requirements and provide examples of projects in which performance was an explicit consideration that led to improvements of code-base designs. Some of these examples were still deterministic in nature. Other examples used probabilistic calculations that consider the likelihood of a disaster occurring, the likely costs of mitigation, and the expected benefits resulting from the mitigation efforts. FEMA has established methods to estimate losses due to seismic events (FEMA, 2012) and for other hazards (FEMA, 2003). These approaches take into consideration a range of possible disasters of varying magnitudes and their respective probabilities of occurrence to gain a holistic understanding of the damage to which the facility may be subjected to during its lifetime. The design team must conduct a thorough cost-benefit analysis to balance potentially greater costs of a more robust structure with improved performance. The probabilistic process discussed above can be repeated for varying levels of robustness in design to determine the optimum balance between additional materials required for construction and probable savings in damage during the facility's life.

As an example of a holistic design approach that takes into account the performance of all aspects of the facility, consider a hypothetical building intended for use as a manufacturing facility in a high seismic zone. This building will likely contain some partitions, many mechanical, electrical, and plumbing (M/E/P) components, many manufacturing components, and much equipment. These components are damaged by different phenomena. The M/E/P components and equipment are subject to damage when the structure they are attached to accelerates too quickly. The partitions, on the other hand, will be attached to two adjacent levels in the structure and will be subject to damage from relative displacements between those two levels (interstory drift). Without considering this during selection of the structural system, one might focus on lateral strength & stiffness and select a stiff steel braced frame system because it can achieve the objectives with less material than a more flexible moment frame. However, the stiffer braced frame system will generate lower drifts and higher structure accelerations during a given seismic event than the comparable moment frame system. Given the sensitivity of a majority of the nonstructural components to damage induced by floor accelerations, the braced frame system will likely cause a much higher level of overall damage to the building in a major event. Although the moment frame system may require a larger initial investment in materials and resources, the analysis may reveal that this initial investment will lead to lower lifetime impacts including a consideration of seismic damage.

RESOURCES FOR RESILIENT DESIGN AND DISASTER MITIGATION

The committee report summarizes and evaluates some of the existing programs that can aid structural engineers and communities in reducing disaster losses. The reader is referred to that document for details. This paper merely lists the programs that were summarized.

- *FORTIFIED for Safer Living and Safer Business* is a voluntary program that provides specific design criteria and the necessary construction and inspection oversight to ensure

© ASCE 2014

resilient structures that are designed to standards beyond the code (FORTIFIED, 2014).

- *High Performance Building Requirements for Sustainability* are "detailed criteria that combine functional resilience with the other key aspects related to the design and construction of green buildings are presented as a compilation of modifications to the International Code Council International Building Code" (PCA, nd; PCA 2010).
- The *High Performance and Integrated Design Resilience* Program was created in 2009 by the Department of Homeland Security. Its goal is "to better prepare buildings and infrastructure to recover from human-caused and natural disaster events such as explosive blasts; chemical, biological, and radiological (CBR) agents; floods; hurricanes; earthquakes, and fires" (HPIDR, 2014).
- *BuildingGreen* (2014) argues that consideration of climate change should influence the way we design our structures, including consideration of energy interruptions and severity and frequency of storms. The blog provides a library of suggestions on how to design for greater resilience.
- The *ATC-58 / FEMA P-58* project proposes a new seismic performance assessment methodology and a computer software program, the Performance Assessment Calculation Tool (PACT), to assist with the calculations (FEMA, 2012).
- The *US Resiliency Council* (USRC) is a non-profit organization that has developed a rating system for evaluating the resilience of individual buildings and for communicating the results to decision-makers (Reis et al., 2012). The Certification of Resilient Engineering (CoRE) Rating uses the ATC-58 methodology and a rating system similar to the Earthquake Performance Rating System (EPRS) developed by the Structural Engineers Association of Northern California (Mayes et al. 2011).
- The *Resilience-based Earthquake Design Initiative* (REDi) Rating System is a framework for owners, architects, and engineers to implement a holistic beyond-code design, planning and assessment approach to facility resilience (ARUP, 2013).

The committee report also lists numerous resources for storm shelters and coastal construction.

In addition, the committee report summarizes funding and policy initiatives for resilience at the federal, state and local level. These provide incentives for communities and owners to build to disaster resilient standards and examples for other communities to follow. These include the following:

- The Housing and Community Development Act of 1974, which authorized communities to use community development block grants to construct tornado-safe shelters in manufactured home parks.
- FEMA's Hazard Mitigation Grant Program (HMGP), which provides grants to state and local governments to fund projects that provide protection to both public as well as private properties.
- FEMA's Pre-Disaster Mitigation (PDM) Program, which provides funding for communities that have an approved hazard mitigation plan.
- The National Flood Insurance Program (NFIP), which provides federally backed flood insurance available in exchange for communities adopting and enforcing floodplain management ordinances.
- A recent legislative effort includes the Disaster Savings and Resilient Construction Act of

© ASCE 2014

2013, introduced into the 113th Congress. This bill intends to provide a tax credit when a structure both meets code and receives a designation as FORTIFIED for Safer Living/Business.

- In 2013, the City of San Francisco signed into law the Mandatory Seismic Retrofit Program for Soft Story Wood Frame Buildings, which will lead to seismic strengthening of vulnerable soft story buildings.

INCORPORATING DISASTER RESILIENCE WITH LIFE CYCLE ASSESSMENT

Merely arguing that disaster resilience is important to sustainability is not good enough. The connection between disaster resilience and sustainability has to be quantifiable. There is an ongoing effort among practitioners and researchers to develop methods and tools to do just this. It is important to remain aware of developments in this area, as it will likely become a more common consideration in everyday structural design.

The Life Cycle Assessment (LCA) methodology is a well-established framework that can be adapted for this task, although traditional LCAs are not conducted with disaster resilience in mind. The Life Cycle Assessment (LCA) methodology, as defined by the ISO 14040 standard (ISO, 2006), is used to quantify and assess many possible environmental impacts, e.g., greenhouse gas emissions, energy used, and water pollution. Although ISO 14040 limits LCA to environmental impacts, LCAs can be extended to include social impacts and economic impacts as well. LCA is a mature and robust methodology. Numerous LCA studies have been performed for buildings and for infrastructure (Cole and Kernan, 1996; Guggemos and Horvath, 2005; Horvath and Hendrickson, 1998; Junilla and Horvath, 2003; Junilla et al., 2006). These studies provided insight to the environmental footprint of different structural and non-structural materials and systems. Various software programs are available for conducting LCAs and there are many professionals qualified to perform LCAs for the built environment.

A relevant methodological distinction in LCA pertains to the way of accounting for environmental impacts. To determine impacts by the bill of materials (or process-based) method, one starts with a bill of materials, consults a database (called a life cycle inventory or LCI), performs an impact assessment for each material or product, and sums the impacts. Although precise, this method requires comprehensive databases that may be proprietary or simply do not exist. It is also not well suited to the conceptual design stage during which member sizes and arrangements are not known. A second method, called Economic Input/Output LCA (EIO-LCA, CMUGDI, 2008), draws from national databases that quantify environmental impacts in various economic sectors as functions of dollars spent. While this method is less exact, it is not as sensitive to missing data and can provide estimates of impacts at the conceptual design level. Hybrid methods combining both approaches have also been proposed.

Although the LCA methodology is mature for buildings and infrastructure, it is not common practice to consider disaster resilience in such studies. None of the major commercial software programs do so, and the profession has only recently begun to discuss the subject. Nonetheless, all of the studies have found that consideration of disaster resilience (or lack thereof) can make a significant difference in the LCA results. The most common approach is to introduce impact estimation into existing methods for seismic loss assessments. There is also potential for these ap-

© ASCE 2014

proaches to be used for durability threats and multi-hazard scenarios. The goal of these methods is to provide decision makers with a range of metrics for the design options under consideration. These metrics include casualties, damage, and business downtime as well as environmental impacts. While this approach does not fall strictly within the LCA methodology as defined by ISO 14040, it seems like the most appropriate for decision making in the context of buildings and infrastructure.

The committee report details current efforts to combine LCA and disaster resilience, divided into efforts from FEMA and ATC (Court et al., 2012), efforts in private practice (Comber et al., 2012; Sarkisyan et al., 2012), and studies by academic researchers. Approaches by private practice and FEMA and ATC have focused on a common set of tools that are familiar to practioners in earthquake engineering. In contrast, academic research has focused on frameworks applicable to any damage type and customized use of fundamental statistical methods. These include ways to merge environmental accounting with seismic loss assessments (Itoh et al., 2006; Russell-Smith and Lepech, 2009), extensions to durability problems and hazards other than seismic (Flint and Billington, 2011), and multi-hazard, time-dependent scenarios (Tapia et al, 2011; Rodriguez-Nikl et al., 2012). These academic studies demonstrate that disaster resilience must be considered to obtain an accurate estimate of environmental, social, and economic impacts of structures on the environment. As compared to the other efforts described earlier, they are more general and make use of fundamental concepts more directly. The efforts from private practice and professional committees use tools more common to practioners and are well suited for drawing rough conclusions for structures early in the design process. Unfortunately, the efforts from private practice are not available to the public (Comber et al.) or not yet well verified (Sarkisian et al.) and the ATC-86 project is not yet completed. For everyday practice, the structural engineer currently has no good options for quantifying the influence that disaster resilient design has on lifetime impacts. However, over the next decade it will be increasingly easier to perform these calculations. Given the rising prominence of sustainability as a design consideration, engineers able to address these concerns will be increasingly in demand.

CONCLUSION

In addition to the topics already mentioned, the committee report concludes with an afterward on developing countries that shares considerations for getting involved in and lessons learned from projects in those countries. It is hoped that the committee report as a whole will motivate engineers to consider the connections between resilience and sustainability, and provide them the guidance necessary for incorporating this work into their daily lives. The committee report provides the following recommendation for those interested in doing more to support disaster resilience and sustainability:

1. **Becoming better informed** by using the references and links in the committee report.
2. **Participating in the code adoption process** to encourage resilient design standards.
3. **Supporting legislation** that requires or provides incentives for resilient construction.
4. **Educating owners** regarding the importance and value of resilient construction.
5. **Advocating with insurance companies** and portfolio managers to offer decreased costs for better performing facilities.

© ASCE 2014

REFERENCES

AFP (2011). "Catastrophes cost economy $350bn in 2011: Swiss Re", News Release, Dec 15, 2011, Agence France Presse.

ARUP (2013). REDi Rating System: Resilience-based Earthquake Design Initiative for the Next Generation of Buildings, ARUP, San Francisco, CA.

Bocchini, P., Frangopol, D.M., Ummenhofer, T., and Zinke, T. (2013). "Resilience and Sustainability of the Civil Infrastructure: Towards a Unified Approach", *J. Structural Engineering*, accepted for publication, posted ahead of print July 1.

Bruneau, M., Chang, S., Eguchi, R., Lee, G. O'Rourke, T, Reinhorn, A., Shinozuka, M., Tierney, K., Wallace, W., and von Winterfeldt, D. (2003). "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities". *Earthquake Spectra* 19(4), 733-752.

BuildingGreen (2014). BuildingGreen Home Page, <<http://www.buildinggreen.com>>, Accessed March 2014.

CMUGDI (2008). Economic Input-Output Life Cycle Assessment (EIO-LCA), US 1997 Industry Benchmark model [Internet], Available from:<http://www.eiolca.net> .

Cole, R. J., and Kernan, P. C. (1996). "Life-cycle energy use in office buildings." *Building and Environment*, 31(4), 307-317.

Comber, M. V., Poland, C., and Sinclair, M. (2012). "Environmental Impact Seismic Assessment: Application of Performance-Based Earthquake Engineering Methodologies to Optimize Environmental Performance." *Proc. 2012 Structures Congress*, American Society of Civil Engineers, Reston, VA, 910–921.

Court, A., Simonen, K., Webster, M., Trusty, W., and Morris, P. (2012). "Linking Next-Generation Performance-Based Seismic Design Criteria to Environmental Performance (ATC-86 and ATC-58)", *Proc. 2012 Structures Congress*, American Society of Civil Engineers, Reston, VA, 922–928.

CRS (1997). Oceans & Coastal Resources: A Briefing Book, Congressional Research Service Report 97-588 ENR, <<http://www.cnie.org/NLE/CRSreports/BriefingBooks/Oceans/>>, accessed Sep 2013.

Elkington, John (2004). "Enter the Triple Bottom Line, in Adrian Henriques and Julie Richardson (ed), *The triple bottom line: does it all add up?*, Earthscan, Sterling, VA.

FEMA (2000). *Planning for a Sustainable Future: The Link Between Hazard Mitigation and Livability,* FEMA 364, Federal Emergency Management Agency, Washington, DC.

FEMA (2003a). *HAZUS-MH MR4 Technical Manual*, Federal Emergency Management Agency, Washington, D.C.

FEMA (2012) *Seismic Performance Assessment of Buildings: Volume 1 – Methodology*. FEMA P-58, Federal Emergency Management Agency, Washington, DC.

Flint, M. M., and Billington, S. L. (2011). "A Probabilistic Framework for Performance-Based Durability Engineering: Application to Corrosion in Reinforced Concrete." *Proc. 2011 Structures Congress*, American Society of Civil Engineers, 1949-1960.

FORTIFIED (2014). FORTIFIED Home Page, <<https://www.disastersafety.org/fortified-main/>>, Accessed March 2014.

Guggemos, A. A., and Horvath, A. (2005). "Comparison of Environmental Effects of Steel- and Concrete-Framed Buildings." *J.Infrastructure Systems*, 11(2), 93-101.

Horvath, A., and Hendrickson, C. (1998). "Steel versus steel-reinforced concrete bridges: environmental assessment." *J. Infrastructure Systems*, 4(3), 111-117.

HPIDR (2014). High Performance and Integrated Design Resilience Program Home Page, <<http://www.dhs.gov/high-performance-and-integrated-design-resilience-program>>, Accessed March 2014.

ISI (2014). Home Page, Institute for Sustainable Infrastructure, <<http://www.sustainableinfrastructure.org/rating/index.cfm>>, accessed March 2014.

ISO. (2006). *Environmental management - Life cycle assessment - Principles and framework*, ISO 14040. International Organization for Standardization, Geneva.

Itoh, Y., Wada, M., and Liu, C. (2006). "Lifecycle environmental impact and cost analyses of steel bridge piers with seismic risk", in M. Augusti, G., Schuëller, G.I., Ciampoli, ed., *Safety and Reliability of Engineering Systems and Structures*, IOS Press, Farifax, VA.

Junnila, S., and Horvath, A. (2003). "Life-Cycle Environmental Effects of an Office Building." *Journal of Infrastructure Systems*, 9(4), 157-166.

Junnila, S., Horvath, A., and Guggemos, A. A. (2006). "Life-Cycle Assessment of Office Buildings in Europe and the United States." *Journal of Infrastructure Systems*, 12(1), 10-17.

Kestner, D.M., Goupil J., and Lorenz, E., editors (2010). *Sustainability guidelines for the structural engineer*, ASCE, Reston, VA.

Kneer, E., and Maclise, L. (2008). "Consideration of Building Performance in Sustainable Design: A Structural Engineer's Role." *SEAOC Convention Proceedings*, Structural Engineers Association of California.

Larsen, L.; Rajkovich, N.; Leighton, C.; McCoy, K.; Calhoun, K.; Mallen, E.; Bush, K.; Enriquez, J.; Pyke, C.; McMahon, S.; and Kwok, A. (2011). *Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions,* University of Michigan; U.S. Green Building Council.

LEED (2014). LEED Home Page, <<http://www.usgbc.org/leed>>, accessed March 2014.

Mayes, C. R., Hohbach, D., Bello, M., Bittleston, M., Bono, S., Bonowitz, D., Cole, C., McCormick, D., Reis, E., and Stillwell, K. (2011). "SEAONC Rating System for the Expected Earthquake Performance of Buildings." *SEAOC Convention Proceedings*, Structural Engineers Association of California.

MMC (2005), *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities*, Multihazard Mitigation Council of the National Institute of Building Sciences, Washington, DC, << http://www.floods.org/PDF/MMC_Volume1_FindingsConclusionsRecommendations.pdf>>, accessed Sep 2013.

NAS (2012), *Disaster Resilience: A National Imperative*, National Academy of Sciences, National Academies Press, Washington, D.C., <<http://www.nap.edu/catalog.php?record_id=13457>>, accessed Sep 2013.

NIAC. (2009). Critical Infrastructure Resilience: Final Report and Recommendations, National Infrastructure Advisory Council, Department of Homeland Security, Washington, D.C., <<http://www.dhs.gov/xlibrary/assets/niac/niac_critical_infrastructure_resilience.pdf>>, accessed Sep 2013.

NIBS (2012). "Natural Hazards and Security", National Institute of Building Sciences, Whole Building Design Guide, National Institute of Building Sciences, Washington, D.C., <<http://www.wbdg.org/design/resist_hazards.php>>.

NOAA (2012). "Billion Dollar Weather/Climate Disasters", National Oceanic and Atmospheric Administration, << http://www.ncdc.noaa.gov/billions/>>, Accessed Sep 2013.

© ASCE 2014

PCA (nd), *Functional Resilience: Prerequisite for Green Buildings*, Portland Cement Association, <<http://www.cement.org/codes/pdf/HPBRS_prerequisites.pdf>>, accessed Sep 2013.

PCA (2010), *Proposed Amendments to the International Building Code, 2009 edition, Relating to High Performance Building Requirements for Sustainability*, Portland Cement Association, Skokie IL, <<http://www.cement.org/codes/pdf/HPBRS%20&%20Commentary%20v2.0.pdf>>, accessed Jan 13, 2013.

PPD (2013). Presidential Policy Directive – Critical Infrastructure Security and Resilience, PPD-21, the White House, Washington, D.C., <<http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil>>, accessed Sep 2013.

Reis, E., Von Berg, E., Stillwell, K., and Mayes, R. (2012). "The U.S. Resiliency Council Principles of Formation", *SEAOC Convention Proceedings*, Structural Engineers Association of California.

Rodriguez-Nikl, T., Christiansen, J., and Walters, K. (2012). "Reliability-Based Life Cycle Assessment of Green Concrete Structures", in Holland, T., Gupta, P., and Malhotra, V.M., eds., *Recent Advances in Concrete Technology and Sustainability Issues*, SP-289, American Concrete Institute, Farmington Hills, MI.

Rodriguez-Nikl, T., Comber, M., Foo, S., Gimbert Carter, S., Koklanos, P., Lemay, L., Maclise, L., VanGeem, M., and Webster, M. (in press). "Disaster Resilience and Sustainability", SEI Sustainability Committee, Disaster Resilience Working Group, ASCE.

Russell-Smith, S. V., and Lepech, M. D. (2009). "Life Cycle Assessment of FRP Seismic Retrofitting." *Proceedings of US-Japan Workshop on Life Cycle Assessment of Sustainable Infrastructure Materials*.

Sarkisian, M., Hu, L., and Shook, D. (2012). "Mapping a Structure's Impact on the Environment." *Proc. 2012 Structures Congress*, American Society of Civil Engineers, Reston, VA , 898–909.

Tapia, C., Ghosh, J., and Padgett, J. E. (2011). "Life Cycle Performance Metrics for Aging Seismically Vulnerable Bridges." *Proc. 2011 Structures Congress*, American Society of Civil Engineers, Reston, VA, 1937–1948.

WCED (1897). "Our Common Future: Report of the World Commission on Environment and Development", United Nations.

wunderground (2013). "Hurricane Archive", <<http://www.wunderground.com/hurricane/hurrarchive.asp>> accessed July 2013.