Environmental Science

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Environmental Project Management

Principles, Methodology, and Processes

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Foreword

Project management is by far more than just a process. It is the method to execute an organisation's strategy, and a framework to get things done in the most cost-effective, schedule-driven and successful way. It is the means to enable innovation, development and execution of new technologies that bring improved benefits into our lives.

The rapidness of technological development is having a real effect on our world, shifting away from traditional professions into completely new roles, through to the way we work, the way we live, play and communicate. Each of these are reliant on, or impact upon, our environment. That includes the source of our food, water treatment, housing, radioactivity, waste management solutions and the depletion of natural resources used for everything we process, manufacture and consume.

This effectively means that a book such as this is not restricted to projects that preserve and improve the environment as one may first think. In fact, projects that involve any form of construction, production, transportation and waste, all need consideration to its effect on the environment.

The most significant impacts on the environment come from the resource sector (e.g., major oil spills out at sea, the devastation on marine habitants, coral and the fishing industry, etc.) or even large construction projects, such as high rise buildings and road highways, which have a direct impact on wildlife, groundwater levels, landscape, soil types and drainage system. Even the damage to our oceans that occupies over 70 % of Earth from the summation of recreational sport, over fishing, tourism, commercial shipping and the mining of oil, gas and minerals activities is also becoming a serious global issue. The reality is that environment covers everywhere we operate, from the sky, to the land and to the river, lake and ocean scape. These all have to consider the balancing of the need for land between housing, public facilities, food production and waste management, as well as the manufacturing needs against available natural resources and the call for improved methods of cleaner production. What is apparent is the growing awareness and requirements for balancing these social-economic and environmental outcomes as a part of good project management process.

Whilst there is an awareness of the many world-wide challenges that vary by geographic and economic position, more intelligent systems and methods for data analysis and international information sharing, such as the use of satellite imaging and geospatial data, is telling us more about mother Earth, enabling early warning of weather conditions, shifts in water levels, and even to the amount of forests remaining on Earth that are visible from space. This book brings together the many facets of knowledge, technology, formula and analytical approaches to enable more informed decision making. Having worked around the globe and seen many of the theories and formula for calculations in project management, this book provides a key resource in bringing together those that have become industry norms and more common practices into a single reference point.

The importance of understanding the technological, economic and social dimensions to deliver environmental-based projects that have short term results and long term impacts, coupled with the desired sustainable outcomes, cannot be understated. Even a high rise structure built in a location susceptible to flooding and earthquakes means changes in engineering design, selection of materials, and foundation preparation, and project management is about creating change.

The book has set a benchmark on the professionalism with which environmental-based projects should be planned, monitored and assessed. Its authors, both from Curtin University, Australia, are highly regarded experts with significant academic credentials, and a thirst for knowledge. Professor Ebenezer (Eben) Sholarin has qualifications in industrial engineering, petroleum economics and environmental management, specializing in Environmental Impacts Assessment (EIA). Eben is also a certified project management professional with over 20 years working experience. Professor Joseph L. Awange has international experience working in Australia, Brazil, Germany, Japan and Kenya. Joseph is a world renowned subject matter expert in the areas of environmental monitoring, Environmental Impacts Assessment (EIA), geodesy, GIS and photogrammetry. He has authored/co-authored numerous books in these fields and is a lead expert of National Environmental Management Authority (NEMA) in Kenya.

Australia
September 2015

Todd Hutchison M.Com., MBA, PMP, FPMIA
Global Chairman of Peopleistic Pty Ltd.

Preface

Today, 22 billion tonnes of green-house gas emissions (methane, nitrous oxide and carbon dioxide) are emitted each year into the atmosphere from man-made sources. These are from burning gas, diesel and oil for power generation, and from flaring and venting during non-routine operations. Over the next hundred years, demand for energy is expected to more than double. Growth will be particularly critical in developing nations, e.g., China, India, Brazil and Venezuela, where industrialization and improved quality of life will increase demand for energy. Scenarios designed to predict future emissions estimate that, unless action is taken to limit emissions by 2100, annual emissions of CO_2 from fossil fuels will range from 16 to 110 billion tonnes per year. Most of these scenarios indicate a doubling of CO_2 emissions by the middle of this century.

Failure to measure and report the outcomes of environmental pollution, climate change and industrial wastes cost Australia alone several billion dollars a year in lost efficiency, repeated errors and unexploited opportunities.

The need to deliver projects within the overall strategic plan of a business organization is a *sine qua non* to increasing shareholders' wealth. However, the spectre of climate change and the daunting challenge of reducing greenhouse gas emissions are changing our collective consciousness.

How can we improve the ways in which projects are planned so that realistic and useful measurement of their outcomes and value for money becomes possible? How can we produce from these evaluations data of the quality and a standard required to drive future improvement? The authors have used the developed environmental project management (EnvPM) methodology to study and propose a sustainable solution to the problems of greenhouse gas emissions, hazardous waste disposal and deforestation.

This book is written as a sourcebook for undergraduate and graduate students, researchers and non-experts interested in environmental project management methodology using geospatial tools. It is intended to raise the bar on the professionalism with which environmental projects are planned, monitored and evaluated.

The book is divided into four parts. Part I: setting for environmental project management, consists of two chapters; part II: principles of environmental project management contains five chapters; part III: essential tools and techniques for environmental project management includes ten chapters and finally, part IV: case studies on environmental conservation and remediation projects combines three chapters together to discuss the case study of environmental projects in Australia and challenges of applying environmental project management in developing countries. Each chapter ends with a concluding remark, summarising vital points discussed.

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Dedication and Acknowledgements

Two people are better than one, because they can reap more benefit from their labour. For if either of them falls down, one can help the other up

—Holy Bible, Eccl. 4: 9–10

E.A. Sholarin would like to thank his wife, Irina Alexandrovna (Irene), for her love, patience and support during the writing of this book. His children, Victor Adetokunbo and Lydia Opeyemi, are his constant inspiration, and the generation to occupy that future we hope to shape for the better. He is also grateful to the School of Petroleum and Chemical Engineering, Curtin University, Australia for creating a supportive and conducive work environment that made the preparation of this book possible.

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Contents

Part IV Case Studies on Environmental Conservation and Remediation Projects

Part I
Setting for Environmental Project Management

Chapter 1
The Need to Protect and Conserve the Environment

Climate change is the single greatest threat to development, and can undermine the progress already achieved in reducing poverty. It is a risk to economies large and small, and to the stability of the global financial system. It raises risks of diminished supplies in much of the world, and it can threaten peace

—Ban Ki-moon, Secretary General of the United Nations

Industrial activities of the past half century have created serious ecological problems. The list includes global warming, ozone depletion, loss of biodiversity, natural resource scarcity, air pollution, acid rain, toxic wastes, and industrial accidents (Brown et al. 1987, 1988, 1989, 1990, 1991, 1992, 1993). These problems are expected to worsen in the next 50 years

The debate over global warming and the momentum on the need to address climate change has been inexorable and accelerating. First, there is solid evidence that suggests the mean temperature at the Earth's surface has been increasing since the start of the modern industrial age (circa 1860), with a total increase of about 0.7 °C (see, e.g., Bucknall et al. 2000, Dincer et al. 2009). Although there are substantial dissenting opinions in this regard (see, e.g., Zedillo 2008, Paltridge 2010), global warming has been widely attributed to greenhouse gas effect caused by the production of carbon dioxide, a byproduct derived from combustion of hydrocarbons. Major governments and international accords such as the Kyoto, Japan, in 1997 have presumed the causal relationship between fossil fuel combustion and global warming.

Emission of harmful substances into the oceans, deforestation of the planet lungs and air pollution has already resulted in serious problems for the entire mankind (see Fig. 1.1). Scientists now believe "it is "extremely likely" that the result of human activities is the dominant cause of global warming, a long-term trend that is clear despite a recent plateau in the temperatures" (IPCC 2013). This is the first time scientists have unequivocally stated (with 90 % certainty) that global warming is a fact, and that human impact is a significant cause (Newman et al. 2009). United Nations Secretary General Ban Ki-moon declared climate change as "the defining challenge of our age" (Rosenthal 2007). President Barrack Obama of the United States of America, in his speech on global warming, puts it more succinctly:

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Fig. 1.1 The effects of deforestation, climate change, and natural disasters on Marovo Lagoon, Solomon Island

"We are the first generation to feel the impact of climate change, and the last generation that can do something about it." (Obama 2014). Such pronouncements fuel the quest for rapid and drastic reductions in greenhouse gas (GHG) emissions and concentrations.

Fossil fuels have offered astounding opportunities during the 20th century especially in the rich countries of the western world, but now, mankind has to face the challenges arising from fossil fuel exploitation. The energy problem is entwined with many social and environmental issues (see, e.g., Othieno and Awange 2016). The fundamental challenge is associated with many vital and entangled questions that we are called to answer, such as:

- should we progressively stop burning fossil fuels?
- how do we mitigate the expected rise in sea levels over the next century against the opportunity cost to government and society?
- will it be possible for all the Earth's inhabitants to reach the standard of living of developed countries without devastating the planet?
- will science and technology alone take us to where we need to be in the next few decades?
- can we execute our projects in a better way with great outcomes for the economy, planet, and its habitats?

Of course, some production facilities cannot be 100 % ecologically clean, and at the same time the humanity has got used to the products and services offered by such enterprises. In such a case, we cannot talk about elimination of harmful substances. However, it is possible to decrease negative impacts of industrial activities on the nature.

This book seeks to address these difficult questions, first, through its application of project management principles, then guide the reader to achieve the best outcome possible, using environmental project management processes, tools, and techniques.

It builds on the Guide to project management body of knowledge (PMBoK Guide), a globally recognised standard for managing mega projects, programs, and portfolio (PMI 2013)—and offers a new framework for handling the challenges of climate change, radiological contamination, carbon, and toxic waste sequestration.

1.1 Environmental Project Management—An Introduction

> *"The future belongs to those who understand that doing more with less is compassionate, prosperous, and enduring, and thus more intelligent, even competitive."—Paul Hawken*

For many years, resource exploration professionals appreciated the basic principles of geology, geophysics, and construction engineering because they are integral parts of the recovery process. Today, these engineers must interface with biologists for habitat management; with atmospheric physicists for air-dispersion issues, and epidemiologists concerning the effects of toxic chemicals and various diseases on workers' health and safety. In addition to these hard "technical disciplines", the softer disciplines (such as leadership, stakeholder management, and project management) cannot be ignored. All these subjects belong in the arsenal of modern project management professional.

Environmentalism has captured a sizeable portion of national and international debate. The debate is often fueled by press notices presenting incidents that cause pollution that may have chronic impact on ecosystems, be it offshore or onshore operations. A life example of this is the devastating situation plaguing the Niger Delta oil region of Nigeria, West Africa. The oil communities had to endure the result of reckless oil production and exploration. This ushered in excruciating environmental conditions, which were often aggravated by oil spills, gas flaring, discharge of waste and water pollution, and other fallout of poor oil field management by the multinational oil companies. The discharge of refinery effluents into fresh water sources and farmlands devastates the environment and threaten human lives. Such effluents contain excessive amount of very toxic material like mercury and chromium. Slowly, but relentlessly, petroleum exploration and production activities such as gas flaring, oil spillage, indiscriminate construction of canals and waste dumping, have brought the human ecosystem of the Niger Delta to the point of near collapse (Aluko 2001). An example of the devastating effect of oil spill on farmlands and vegetation in Nigeria is shown in Fig. 1.2. This is the price the country has to pay for drilling petroleum resources without considering the potential environmental impact.

From an environmental standpoint, Niger Delta oil spill and dumping of hazardous waste was not an isolated event. By 2010 the world had already witnessed dozens of environmental and public health disasters: Kuwait oil well disaster in 1991 in which 650 oil wells were set ablaze spilling almost 1 million tons of oil and killing over 20,000 sea birds, the Lake Nyos CO_2 gas eruption in 1986 releasing 80 million cubic meters of carbon dioxide, killing 1,700 people and 3,500 livestock, and the British Petroleum (BP) Macondo oil well disaster in 2010 killing huge populations of

Fig. 1.2 Forest and farmland covered in a sheen of greasy oil near the Nigerian village of Otuegwe: A case of environmental degradation in Ogoniland, Niger Delta region, River State of Nigeria

marine animals (see Table 1.1). In addition to the foregoing, there are many problems resulting from nuclear waste, including Chernobyl explosion in Ukraine, former Soviet Union in 1986. Evidence of ongoing contamination is presented in Sect. 1.3.

Indeed, much of the current environmental legislations and regulations were formed in an era of confrontation between the extractive industry and respective host governments with command and control regulation as the *modus operandi*. On the other hand, industry has learned by experience that goal setting, management systems, and incident-free operations are the keys to improved performance. For a successful enterprise in this respect, it is imperative that an overlying management strategy integrating *cost, social, and environmental* performance targets at every phase of opportunity development life cycle are implemented. This is the essence of environmental project management.

Traditional environmental project management often does not incorporate environmental factors in the planning documents. The government agencies that are responsible for legislative monitoring and compliance have little or no understanding of the particular industry, where the inspection is being conducted. Even environmental reviews are often conducted without due diligence or prior to conducting feasibility studies and other activities. Moreover, public and environmental officers often become impatient, confused, frustrated over apparent revisiting of previously made decisions, which require the whole process to be revisited all over again.

In order to understand the concept of environmental project management, one must begin with a definition of an environment and then progress to defining a project. Once a project has been defined, it then becomes possible to move further in defining project management and, ultimately, to employ these three definitions to describe environmental project management.

Table 1.1 World's worst environmental disasters showing their corresponding effects

Incidence	Amount spilled	Cost implication	Environmental effect
Macondo—2010, BP Gulf of Mexico, USA	492,000 tones	$5.4 billion possible fines and $21 billion (if gross negligence) (Robertson and Kraus 2010). $20 billion for compensation and clean up (Welch and Joyner 2010)	11 people dead, 997 birds dead; 400 sea turtles dead; 47 Mammals including Dolphins dead
PTTEPA Montara Gas Well disaster, 2009, Timor sea, Western Australia. The worst oil disaster in Australia	4,750 tones of light sweet crude oil for 74 days	Unknown	Unknown
1991 Gulf war in which 650 oil wells in Kuwait set ablaze (Enzler 2006)	1 million tones	Not known	20,000 sea birds killed
1989 Exxon Valdez in Prince Williams Sound Alaska (Cleveland et al. 2010; Cutler et al. 2010; Enzler 2006)	10.9 million gallons	$7 billion for fines, penalties and claims of which over $2.1 billion used for clean up	Casualties include 250,000 sea birds, 2,800 sea otters, 250 bald eagles and 22 killer whales
1986 Lake Nyos Limnic eruption, Cameroon, West Africa	80 million cubic metres of carbon dioxide	Not known	1,700 people dead. 3,500 livestock dead
Ixtoc, 1-1980, Gulf of Mexico, USA	454,000 tones	Unknown	Unknown
1978 Amoco Cadiz off the coast of Brittany, France (Bourne 1979; Boyes and Enzler 2006)	230,000 tones of light crude	$282 million of which $85 million for fine	Killed over 3450 sea birds, fisheries, oysters and sea weed beds were also greatly affected

1.1.1 What Is Environment?

"The environment is everything else except me"—Albert Einstein

In this section, the concept of environment and its possible definitions are presented. The word *environment* has different meaning in different jurisdictions, and is therefore widely recognized as a broad term with many interpretations and definitions. In Western Australia, for example, the *Environmental Protection Act (EPA) WA* 1986 defines environment as including water, air and land and the inter-relationship which exists among and between water, air and land, and human beings, other living creatures, plants, micro-organism and property.[1] The *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act) on the other hand, which is Australian-wide environmental legislation, defines environment as including[2];

(a) ecosystems and their constituent parts, including people and communities; and
(b) natural and physical resources; and
(c) the qualities and characteristics of locations, places and areas; and
(d) heritage values of places (i.e., places included in the Register of the National Estate kept under the *Australian Heritage Council Act* 2003; and
(e) the social, economic, and cultural aspects of a thing mentioned in paragraphs (a), (b), (c) or (d).

In Canada, the *Canadian Environmental Assessment Act* (CEAA) 1992 define the environment as the components of the Earth, and includes

(a) land, water, and air, including all layers of the atmosphere,
(b) all organic and inorganic matter and living organisms, and
(c) the interacting natural systems that include components referred to in paragraphs (a) and (b).

In general, therefore, the term '*environment*' may be used narrowly, with reference to '*green*' issues concerned with nature such as pollution control, biodiversity, and climate change; or more broadly, including issues such as drinking water and sanitation provisions (often known as the '*brown agenda*') (Nunan et al. 2002). For instance, Neefjes (2000, p. 2) uses the term in a broad sense, referring to the environment as a vehicle for analysing and describing relationships between people and their surroundings, now and in the future, while Bucknall et al. (2000, p. 3) points out that the word environment generally refers to a natural resource base that provides sources and performs sink functions, and uses a broad definition of the environment in his background paper to the World Bank's Environment Strategy (Nunan et al. 2002).

Owing to the varied definitions of the term environment, certain terms and expressions that relate to it such as environmental degradation, environmental change, and environmental quality are also problematic in that they vary widely in usage within and between disciplines, and several have been used as synonyms (e.g., Johnson et al. 1997). In an attempt to correct the problem and standardize usage, Johnson et al. (1997) defines or redefines 10 of the most common environmental terms, e.g., *natural environment* and *environmental change* are defined on the basis of what is meant by natural as reflected by common usage and dictionary entries while *environmental degradation*, *land degradation*, and *soil degradation*, are defined as any change or disturbance to the environment, land, or soil perceived to be deleterious or undesirable. In part III of the book, we will encounter some of these terms and how they are linked to environmental project management.

[1] EPA 1986, Sect 2(a).
[2] EPCA 1999, Sect. 528, Definitions.

1.1.2 What Is a Project?

"I don't work on a project unless I believe that it will dramatically improve life for a bunch of people"—Dean Kamen.

The definition of a project has been the subject of considerable debate among project management professionals, researchers, and associations. Dinsmore and others define a project as a *complex effort* involving interconnected activities, with the purpose of achieving an objective, and a temporary, non-repetitive process (see e.g., Dinsmore and Cabanis-Brewin 2006; Khatib 2003; Lewis 2000; Nicholas 2004). Turner and Westland describe project as a *unique endeavor* to produce a set of deliverables, in which human, material, and financial resources are organized in a novel way, to undertake a unique scope of work, of given specification, within clearly specified time, cost, and quality constraints (Turner 2009; Westland 2006).

The UK Association for Project Management defines project as a set of interrelated tasks that are undertaken by an organisation to meet defined goals (objectives), which have an agreed start and finish time, is constrained by cost and have specified performance requirements and resources (APM 2012). The International Project Management Association (IPMA) defines project as a temporary endeavour with a defined beginning and end (usually time-constrained, and often constrained by funding or deliverables), undertaken to meet unique goals and objectives, typically to bring about beneficial change or added value (IPMA 2006).

Perhaps the most complete definition is found in the Project Management Body of Knowledge (PMBoK) Guide, 5th edition, published in 2013 by the Project Management Institute (PMI). PMI is the world's largest professional project management association with more than 460,000 members and over 660,000 project management professionals (PMPs) worldwide as of July, 2015, with close to 5 million copies of all editions of the PMBoK Guide in circulation (PMI 2015). In the PMBoK guide 2013, a project is defined as "a temporary endeavour undertaken to create a unique product, service, or result. Temporary means that every project has a definite beginning and a definite end. Unique means that the product, service, or result is different in some distinguishing way from all other products, services or results" (PMI 2013, p. 3). Thus, a project can be any new structure, plant, process, system or software, large or small, or the replacement, refurbishing, renewal or removal of an existing one. It is a one-off investment (Smith 2002, p. 2).

Every project has *deliverables*. These are unique and verifiable products, results or capability to perform a service that is identified in the project management planning documentation, and must be provided in form of project verification to complete the project. The deliverable is a visible sign that an activity or task is complete. This sign could be an approving manager's signature, a physical product or document, the authorization to proceed to the next activity, phase, or other indicated sign of completion.

From the definitions provided above, it may be concluded that a project has the following characteristics:

- a complex or ad hoc, one-time endeavor (processes) with a clear life cycle, specific time frame or finite life span, i.e., temporary;
- a defined and unique set of products, services or results, limited by budget, schedule and resources;
- developed to resolve a clear goal or set of goals;
- customer-focused;
- a network of building blocks in the design and execution of organizational strategies;
- terminated upon successful completion of performance objectives.

Project exists in a relatively turbulent environment; change is the purpose of the project itself and uncertainty is inherent in the objectives of that project. Projects can also have social, economic, and environmental impacts that far outlast the projects themselves (PMI 2013).

1.1.3 What Is Project Management?

"Plan the Work, and then Work the Plan. If you fail to plan, you plan to fail"

Project management is a phrase used to describe a *planned*, *methodical approach* to project completion. Such an approach emphasizes "front-end" planning in order to minimize problems in the later stages of the project, as well as emphasizing control of timing and spending. It is an add-on to general management, meaning that it cannot readily exist or be effective without a solid management base. Although it requires its own methodology to bring to bear, in general, it provides the means of focusing attention on a specific goal, task or target. Project management deals with the application of knowledge, skills, tools and techniques to the planning, coordination, and reporting of project activities with a view to meeting project requirements. Projects bring about change and project management is recognized as the most efficient way of managing such change (APM 2012, p. 3).

Thus, project management can be defined either as a *process* (e.g., input and output process, cause-and-effect process) or *toolbox* for executing different functions (e.g., planning tool, monitoring and control tool, resource optimization tool).

Badiru (2008), for instance, describes project management as the process of managing, allocating, and timing resources in order to achieve a given objective in an expedient manner. The objective may be stated in terms of time (schedule), performance requirements (quality), or cost (budget). It is the process of achieving objectives by utilizing the combined capabilities of available resources. Havranek (1999) on the other hand, describes project management as the "art and science of planning, organizing, integrating, directing, and controlling all committed resources—throughout the life of a project—to achieve the predetermined objectives of scope, quality, time, cost, and customer satisfaction". The ultimate benefit of implementing project management principles is having a satisfied customer, whether in form of an individual, community or an organisation. Completing the full scope of work of the project in a quality manner on time and within budget provides a great feeling of satisfaction. When projects are successful, everybody wins!

It is in view of the above that project management institute (PMI) defines project management as the "application of *knowledge*, *skills*, *tools* and *techniques* to project activities to meet project requirements" (PMI 2013). Australian institute of project management (AIPM), on the other hand, defines project management as "the integration of project activity through the project life-cycle to achieve the delivery of a defined product or service within prescribed constraints of time, budget, scope and quality" (AIPM 1996), while project management is defined in the UK Association for Project Management Body of Knowledge as the "application of processes, methods, knowledge, skills and experience to achieve the project objectives"(APM 2012). The challenge in large companies is to provide guidelines for managing project activities and a consistent procedural framework, both for individual projects and across projects. This enables leaders from all specialities to work together and communicate with one another (Salazar-Aramayo et al. 2013).

Project management in the environmental restoration and remediation industry comes with a unique set of challenges involving the management of engineering, technology, science, cost, schedules, procurement, risk, safety and environment, personnel, and communication. The general approach for resolving the challenge is to empower an environmental manager, who possesses leadership attributes to become a project manager through informal mentoring and the professional acquisition of lesson learned from his/her own work experiences.

Managing a project implies planning and monitoring its execution, enabling objectives to be achieved. Project management no longer has a specific focus (managing projects), but rather has become an organisational skill that permeates all levels of the company (Kerzner 2010; Lewis 2000; Nicholas 2004; PMI 2013; Westland 2006). The need for project management is no longer debated, but rather what form it will take (tools, techniques or processes) (IPMA 2006).

1.1.4 The Importance of Project Management

> *"The balance between the global supply and demand for crude oil is becoming progressively tighter, increasingly requiring our industry to face new and unique challenges. Our industry of tomorrow will have to address the demands of operating in an adverse environment, development of new technologies and expediting implementation in the field, as well as optimization of processes and enhancing collaborative efforts to reduce cost"*[3]

The critical role of project management as a key enabler of organisational strategy to implement projects successfully has been widely established in areas such as the

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[3]This was a very inspiring statement made by the former president of Society of Petroleum Engineers, Dr Behrooz Fattahi at his University of Western Australia presentation on "Challenges of the Future", delivered on the 7th April, 2011.

planning and control of *time*, *resources*, *cost* and *quality*. Sixty years ago, project management was confined to the Department of Defence contractors and construction companies (see, e.g., Bowman 1967; Chapman 1973; Mungo 1967). Today, the concept behind project management is being applied in such diverse industries and organisations such as defence, construction, pharmaceutical, petro-chemicals, mining, banking, hospitals, advertising, information technology, state governments, local governments, and the United Nations.

Majority of literature on management science stresses the importance of project management as an efficient tool to handle novel or complex activities. Kerzner (2010), for example, has suggested that it is more efficient than traditional methods of management, such as the practice of functional divisions in a formal hierarchical organisation. The process of bringing new projects on stream and into the market imposes demands on established organisations and necessitates different management techniques from those required to maintain day-to-day operations. In such circumstances, where companies have a finite, unique and unfamiliar undertaking, the techniques of project management can be successfully implemented. These undertakings would call for more and faster decision making techniques than possible in a normal operation and making the right choices will be critical to company success.

The use of modern project management has become associated with such novel complex problems, which are inevitably called a project. Consequently, the success of project management has often been associated with the final outcome of the project. Project management and project success are not necessarily directly related (Munns and Bjeirmi 1996). A project is considered successful when it is carried out within the desired deadline, budget and quality level, meeting the expectations of the primary stakeholders. At this point, the work of Baccarini (1999) and Cookie-Davies (2002) is particularly relevant in distinguishing between “project management success” and “project success”.

Specifically, project management success is measured against the widespread and traditional measures of performance (cost, time, and quality), and project success is measured against the overall objectives of the project, which is the customer’s overall satisfaction with project outcome. This is considered the most significant, if not the single most important success factor (Havranek 1999). This implies that project success cannot be measured until after the project is completed. By contrast, project performance can be measured during the life of the project. IPMA (2006, p.40) defines project management success as “the appreciation of the project management results by the relevant interested parties”. Thus, “project management success” is synonymous with “project management performance”, because the interest is in assessing management performance and not project results.

There are many projects, where everything is done by the book, even applying the PMBoK guide, but the customer (society, government or investor) is left unsatisfied. For example, there is no point in finding substantial reserves of oil, gas or minerals and in successfully developing them unless the product or result can be disposed at a realistic price, thus generating cash revenue to pay operating costs, to meet the requirements of the host government’s “take” (i.e., taxes, royalties or share of production), minimize the environmental impact of the exploration venture on the ecosystems, and duly recover the capital committed to the venture. To believe otherwise would be likened to the old medical saying: "the operation was a success, but the patient died". A project cannot be considered successful if it fails to meet the sustainability (economic, social, and environmental) objectives. The best approach of judging project success is not only by using the traditional measures of "on time, on budget, and on target", but rather to assess the project outcome based on the "product sustainability" success, i.e., a sustainable outcome both for current and future generations.

Indeed, project management plays a major role in achieving successful business results and a sustainable outcome. Key problem solving skills and techniques relevant to the environmental restoration and remediation industry include; scoping, environmental planning, estimating, modelling, organising, monitoring and controlling the environment with a view to optimising project performance targets. In addition, teamwork, motivation, contracts, negotiations, risk assessment, handling data, and documentation are essential requirements for a successful project.

Managing the complexity of major capital projects in today's natural resource landscape has never been more critical. Against the backdrop of a decline in both global economic conditions and corporate revenues, stakeholders are demanding improved return on investment (ROI), reduced risk exposure, and greater transparency.

1.2 Environmental Protection, Conservation, and Remediation

"We are the first generation to feel the effect of climate change and the last generation who can do something about it"—Barack Obama.

Section 1.1.1 defined the overall concept of environment. In this section, attempt is made to discuss its protection, conservation and remediation, if pollution or contamination occurs. This is necessary given the tremendous advancement in economy and technology leading to exploitation of environmental resources (see, e.g., Fisher 2014), which has led the contemporary world to be caught up in the web of unprecedented environmental challenges (e.g., Magnani 2011). For example, China's environmental crisis is argued to have been triggered by an increased environmental degradation resulting from its economic growth of almost 10 % annual increase in gross domestic product (GDP) in the past three decades (Yale Center for Environmental Law and Policy 2006). As a result of their development and economic growth, developed nations such as Australia, USA, and Germany have created severe environmental problems that are of global concern. These environmental problems, as reported, e.g., by Liu and Diamond (2005) are responsible for health issues, economic losses, and social conflicts. These countries, among others, are beginning to promote campaigns and debates on *environmental protection and conservation* through discussions on sustainability and fundamental changes in policies and regulations.

1.2.1 Environmental Protection

United Nations (1992) defines *environmental protection* as "any activity that maintains or restores the quality of environmental media through preventing the emission of pollutants or reducing the presence of polluting substances in environmental media". In general, therefore, *environmental protection* can be viewed as the guarding of the ecosystem and its constituents from undesirable changes due to both natural (phenomenon and/or forces) and human activities. This is mostly done in terms of legislations, i.e., Acts of Parliament made to regulate the relationship between people's activities and the environment. Fisher (2003) summarises it very well;

> "*Environmental protection is thus all about regulating human activities that pollute and harm the environment*".

Fisher (2003) then argues that environmental protection means little without answering the question: "protecting the environment from what"? Originally, according to Fisher (2003), and as seen from the definitions above, the straight forward answer to the question was protecting the environment from pollution matters and waste that can be emitted into water or the atmosphere, thereby degrading the environment. Various Acts that regulate environmental protection within Australia, e.g., the *Environmental Protection Act* 1986 (WA), *Environmental Protection Act* 1986 (Victoria), and *Waste Management and Pollution Control Act* 1998 (Northern Territory), for example, are all underpinned by waste and pollution as the focus parameters (issues). This school of thought is however changing. Modern views recognises that our environment undergoes various forms of degradation and need to be protected. The degradation could take various forms, e.g., burning of fossil fuels, pollution, deforestation, biodiversity loss, radiation spills or nuclear accidents, exhaust fumes from vehicles, etc. Environmental protection, therefore, is essential to the well-being of the population and its major purpose is to contribute to sustainable development through various legislations, e.g., pollution control, guarding purity of native species, and controlling the access rights to exploitation of the environmental resources as already pointed out in Fisher (2003).

Due to various forms of human activities, environmental protection is needed and as Liu and Diamond (2005) points out, it should be treated as an integral part of sustainable economic development. In these regard, the Western Australia's *Environmental Protection Act (EPA)* 1986 (WA) provides for the prevention, control, and abatement of pollution and environmental harm, for the conservation, preservation, protection, enhancement and management of the environment. International environmental protection organizations such as the United State's Environmental Protection and the United Nations Environment Programme agency are few organisations committed to environmental protection issues at global scale.

Among the so many objectives of *EPA* 1986 (WA) are; to promote environmental awareness within the community and to encourage understanding by the community of the environment, to provide advice on environmental matters to members of the public, to publish reports on environmental matters generally, etc. Also in the last decade for instance, China's policies on environmental protection and sustainable development have been significantly improved, realistic steps and measures have been taken to foster environmental protection, which include; adjustment of economic structure, reform of energy policy, development of environmental industry, pollution prevention and ecological conservation, capacity building, and international cooperation and public participation (Zhang and Wen 2008).

Environmental protections actions could be achieved under the following four instruments of control (see, e.g., Gunningham and Grabosky 1998; Macintosh and Hamilton 2008; Zhang and Wen 2008):

- Regulatory/command and control measures: Here, legally enforceable prohibitions are used and can take on various forms, e.g., prohibiting a specific activity, requiring participants to obtain state approvals for specific activities, laying down the procedure for specified activities, requiring a specified group of people to perform specified actions deemed fit for the environment. They are the most common and widely used tools for environmental protection.
- Economic instruments/market-based measures: These are measures that aim to make cost of pollution integral to the production cost of various actors. It is achieved by imposing penalties (monetary) on industries that emit pollutants in excess of prescribed levels, giving monetary incentives, e.g., tax waivers to those doing clean productions, and creating transferable and tradable rights, e.g., carbon trading.
- Voluntarism/Voluntary action measures: An entity has a choice on whether to participate but incentives are provided to those participating. They can range from (i) polluters acting on their own without involving the government, e.g., implementing ISO environmental management systems, (ii) voluntary public programs where the regulator determines the eligibility of participants, to (iii) bilateral agreements between polluters and regulators.
- Public participation/Information and education instruments: Includes those actions that promotes environmental protection through improving of public awareness and understanding of environmental protection issues and challenges. Various environmental protection and sustainability reports by governments and non-governmental organisations fall into this category. Their main disadvantage is passiveness; they rarely address the root cause of environmental degradation.

There is little evidence to suggest that various forms of environmental regulations instrument, when used in isolation, have the capacity to deliver tangible environmental improvements when applied to matters of ‘non-point’ source pollution. Indeed, there is a substantial body of evidence reviewed (see, e.g., Barr and Cary 1992; Gordon 2003; Gunningham and Sinclair 2004; Harrison and Antweiler 2003) which suggests quite the contrary. Unless landholders have a self-interest in engaging in the desired environmental improvements, then information, education, and voluntarism alone will usually be unable to overcome the cost barriers (and sometimes conservatism) that often inhibit change. For these reasons, such measures should not be used as “stand alone” approaches for reducing ‘non-point’ source environmental pollution. As Cohen (1998) pointed out:

"Economic instruments can be used to create incentives to meet or exceed centrally mandated standards. They can perhaps reduce the enforcement and compliance costs associated with criminal justice models of regulation. The difference between the economic instrument and command and control regulation is that incentives and markets were used to move firms towards compliance. And while levels of compliance were perhaps higher than that achieved with command and control regulation, economic instruments still required public bureaucracies to monitor and ultimately to enforce the standards."

Education, training, and voluntarism, may, nevertheless, have value in providing an important underpining to other more interventionist approaches, and the necessary understanding without which landholders and others are unlikely to accept the need to change their practices. What those more interventionist measures should be, how they should be designed, implemented and enforced, and in what source of sequence, and how to steer a middle course between the often competing demands of effectiveness, efficiency, equity and public acceptability should be the main subject matter of environmental project management.

Examples of environmental protection is seen in the *Canadian Environmental Protection Act* (1999), which protects the environment through isolation of pollution and/or contamination sources, e.g.,

- *Pollution prevention plan*: Provides action plan against substances or group of substances and/or processes associated with these substances.
- *Controlling toxic substance*: Categorises substances in form of lists based on their toxicity levels. Also specifies quantities that can be released into the environment alone and/or in combination with other substances. In case of entry/release into the environment, the Act calls for pollution prevention action. It also prohibits export of items on export control list.
- *Animate products of biotechnology*: Deals with the introduction of non-native species into Canadian environment, and ensures the protection of environment (ecosystem) by guarding against release of toxic quantities of living organisms that are not indigenous. Provides accepted list of organisms and ways of seeking permit and conditions to be adhered to in order to bring in new organisms.
- *Controlling pollution and managing waste*: The Act identifies various chemicals and/or pollutants and outlines how they are to be used and disposed. It prohibits importation, use or manufacture of cleaning products (chemicals), water treatment chemicals, and nutrients (compounds, which if released into water would provide nourishment for growth of aquatic vegetation) in concentrations greater than prescribed for the product. The Act also protects marine environment from land-based sources of pollution, implements 1996 Protocol to the Convention on Prevention of Marine Pollution by dumping of waste and other materials, and prohibits export, import, and loading in Canada for disposal in waters within Canadian jurisdiction or use of a Canadian vessel for disposal in the international waters. The Act further provides standards for fuel and fuel products, vehicles, engine and equipment emission. Any adulteration of fuel or substandard vehicles, engines and equipment are prohibited in order to protect the environment. Also, pollution of international water and air is prohibited and measures are laid down on course of action to be

taken in case it happens. Finally, the movements of hazardous waste and hazardous recyclable materials are prohibited without appropriate permit even for transit.

- *Public participation*: Public participation is given a prominent role in this Act through (i) provision for establishment of environmental registry where all the environmental related information is accessed, (ii) giving private citizen the power to apply for investigation if they feel an environmental offence has been committed, (iii) giving private citizens power to bring an environmental protection action, if the minister fails to act on application for investigation, by going to court, and (iv) provision of power to seek for compensation if one is aggrieved (or about to be aggrieved) by the Act, by going to court.

From the Act's point of view, dealing with pollutants directly and environment indirectly makes it more effective, clearer, and more focussed on protecting the environment. It does that in fewer articles compared to if one were to deal with environment directly and the pollutants indirectly.

1.2.2 Environmental Conservation

As opposed to environmental protection discussed in Sect. 1.2.1, which seeks to protect the environment from harm, e.g., from pollutants, Fisher (2003) sees *environmental conservation* as protection of environmental values, e.g., nature reserves, endangered species, etc. Infact, in distinguishing conservation from preservation, Fisher (2003, p. 301) states that conservation protects from harm with an aim of future use. The aspects of protecting with the aim of future use leads to the concept of sustainability that provides an alternative definition of environmental conservation as the rational use of the environmental resources in a sustainable manner (e.g., Heap 1986; Macintosh and Hamilton 2008).

Environmental conservation restricts the freedom of exploitation of environmental resources to ensure it happens in a sustainable framework. For it to be effective, it requires political goodwill, it has to meet scientific criteria of accounting and proofs of existence, and enforceable legal obligations. The sustainable exploitation of environmental resources is ensured by use of various sections of the Environmental Protection and Conservation Acts of various countries, e.g., *Environment Protection and Biodiversity Conservation (EPBC) Act* 1999 (Australia) as highlighted below. The environmental problems in the world today could be seen as man's attitude towards the environment. Various forms of human activities, e.g., gas flaring, bush burning, deforestation, pollution, etc., impact the climate leading to droughts, floods, and extremes of heat and cold. Since unsustainable practices impact natural ecosystems, conserving the environment is essential. For example, the Australian *EPBC Act* (1999) provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places defined in the Act as matters of national environmental significance. *EPBC Act* (1999) among other things seeks to; conserve Australia's biodiversity, protect biodiversity internationally by controlling the international movement of wildlife, provide a streamlined environmental assessment and promote ecologically sustainable development. For instance, one way the Act seeks to conserve private land is through granting tax concession to people who have entered into conservation covenant. A conservation covenant according to the Act, 'is a voluntary agreement made between a landholder and an authorised body (such as a Covenant Scheme Provider) that aims to protect and enhance the natural, cultural and/or scientific values of certain land. The owner continues to own, use and live on the land while the natural values of an area are conserved by the landholder in partnership with the Covenant Scheme Provider'.

Others include a conservation agreement. According to the Act, 'it is an agreement between the Australian Government Environment Minister and another person for the protection and conservation of biodiversity in an area of land or sea'. A conservation agreement may provide for activities that promote the protection and conservation of the following biodiversity; the world heritage values of declared World Heritage properties, the environment in respect of the impact of a nuclear action on the environment in a Commonwealth marine area, and the environment on Commonwealth land, etc. Examples of how the *EPBC Act* (1999) conserves the environment include:

- the provision for *identification and monitoring* of biodiversity as a first step to its conservation and sustainable use. This is done through (i) inventory of threatened species (and amendment of the inventory lists), and (ii) preparation of biodiversity plans. Though not a legislative instrument, the plans show biodiversity components, distribution, and conservation status. Biodiversity plans provide prioritise, strategies, and actions for conserving the environmental resources. Various liabilities are set out against interfering with listed threatened species; these includes trading in members of a listed threatened, critical, and or migratory species, and the liabilities range from 500 to 1000 penalty units.
- use of *conservation advice*, a document listing categories of species or communities, actions to be carried out to stop its decline, and support its recovery is one of the legal provisions of this Act for ensuring conservation. In addition, a wildlife conservation plan for protecting, conserving, and managing; listed migratory species, listed marine species, cetacean in the Australian sanctuary, and conservation dependant species are also provided for.
- protection and preservation of the purity of Australian species through control of non-native species, their dealing, and/or presence within Australia and prohibits trading in those species that may interfere with Australian species. It also provides regulations (covering both commercial and non-commercial exploitation) on dealing with international movement (importation and exportation) of wildlife (both native and non-native) specimen. Ensures compliance with Convention on the International Trade in Endangered Species (CITES) and biodiversity convention, which protects wildlife affected by trade, promote wildlife conservation in Australia and other countries, involves export of Australian native wildlife in an ecologically sustainable manner, and provides for ethical conduct during research involving wildlife.

- provision for access, management, and conservation of biological resources. Controlled access is provided by regulations ensuring access rights and equitable share of the benefits. The indigenous community is granted limited access (rights) to exploit wildlife for food. Also, conservation agreements are provided for between the government and other conservation bodies. Finally, the management of protected areas, i.e., Parks, world heritage listed locations, and reserves are also legislated.

Environmental conservation Acts, e.g., the Antarctic treaty system, Environment *EPBC Act* (1999) of Australia, and *Canadian Environmental Protection Act* (1999) among others, majorly aims at sustainable exploitation of environmental resources by ensuring; (i) maintenance of a healthy level for harvested species/phenomenon, (ii) maintenance of ecological relationship between harvested, dependent, and related populations of environmental resources, and (iii) prevention of irreversible change in the ecosystem. Restoration of environment to some previous state is not conservation but environmental re-mediation, which we discuss next.

1.2.3 Environmental Contamination and Remediation

> *"We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect."—Aldo Leopold.*

Having defined environmental protection and conservation from the regulatory and legal point of view, it is necessary to discuss how pollution or contaminants can be remedied if it does occur.

Environmental remediation (often called *cleaning up* in the environmental industry) refers to the removal of contaminants from environment generated by contaminated soil, industrial wastes, groundwater, sediment, or surface water so as to minimise their impacts on human health and the environment. Although, it is impossible to prevent all chemical spills, intentional releases, natural disasters and accidents that lead to contamination, prevention is still a primary goal of most governments and industries.

Havranek (1999, p. 1) describes environmental remediation as the "performance of engineering/construction projects designed to remedy or restore environmental media, particularly soil and groundwater, degraded by chemical compounds (or elements) that may pose a threat to human health and the environment". This would mean that once requested by the government or a land remediation authority, immediate action should be taken as this can impact negatively on human health and the environment. The fundamental goal of remediation should be to render a site acceptable and safe for long-term continuation of its existing use and maximise to the extent practicable its potential future uses.

According to the OECD (2008), Australia is one of the highest producers of waste in the world, generating waste at a rate of over 2 kg per person per day, the majority

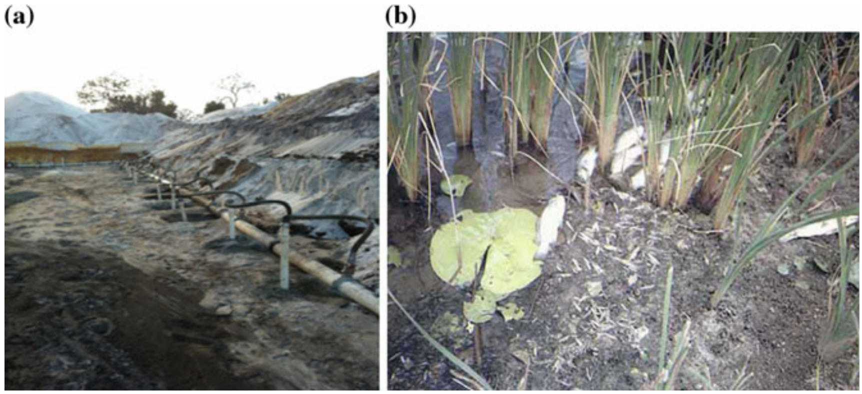

Fig. 1.3 Contaminated land and acid sulphate soil. **a** Photo showing a contaminated land: Consequence of resource exploration and production activities. *Source* http://www.pendragonenvironmental.com/Contaminated-Land.aspx. **b** Photo showing the effect of sulphate soil disturbance on fish and other aquatic organisms. A massive fish kill was associated with the breaking of an extended drought in November 1995. *Source* QASSIT, Qld Department of Natural Resources and Mines

of which ends up in landfill, causing the land and soil to be contaminated with acid sulphate and other pollutants. Example of the devastating effect of industrial activities on Australia's land is shown in Fig. 1.3a.

Often, the most visually obvious effects of acid sulfate soil disturbance are on fish and other aquatic organisms. Run-off transport, the acid from acid sulfate soils to local waterways, exposes aquatic animals to rapid changes in pH, toxic levels of aluminium, iron precipitation, and low dissolved oxygen levels (Cappo et al. 1995). The photo in Fig. 1.3b illustrates this process, which occurred in south-east Queensland in the Pimpama River. The management of municipal and industrial wastes has long been recognised as a key issue in environmental sustainability.

In view of the above, environmental remediation of contaminated land and soil must incorporate the views of the public and a review of the environmental footprint in addition to the standard factors including cost, feasibility, and protection of human health and the environment.

In the past, many exploration and production activities were developed without appropriate consideration of their environmental aspects and impacts. Operations were run in situations in which laws and regulations did not exist or if they did, they were neither adequate nor comprehensive enough. As a result, hazardous contaminated sites were created. Such sites have been created by accidental oil spills during loading, transportation, and unloading operations, improper handling, storage and disposal of industrial wastes, leaks from aging or deteriorated equipments and greenhouse gas emissions. The impacts of oil spills, industrial wastes and carbon emissions are not limited to the direct effect on the ecosystem; it goes a long way to affect the social welfare, aggravates poverty, population displacement, social conflict, production reduction, and also affects the profit margin of the companies involved.

As contaminated sites can ultimately lead to undesired health effects for the surrounding community and its inhabitats, appropriate actions must be taken. Hence the reason for an environmental remediation.

Significant environmental statues that pertain to environmental remediation include:

- *The Environmental Protection Act* 1986 (EPA), WA
- *The Environmental Planning and Assessment Act* 1979 (EP&A Act)
- *The Environment Protection and Biodiversity Conservation Act* 1999 (EPBC act), Australia
- *The Clean Air Act* 1993 (CAA)
- *The Contaminated Sites Act 2003* (CS Act)

Site contamination can occur as a result of the introduction of chemical substances to a site above background concentrations. Environmental protection of oil and gas facilities is the reason for the OPGGS Act. An example is the PTTEPA Montara oil and gas leak in the Timor Sea, off the northern coast of Western Australia (see Sect. 1.3.2). There are several factors that must be considered when determining whether or not the presence of the chemical substances is deemed as site contamination.

Section 1.4 of the *Contaminated Sites Act* 2003 (CS Act) defines site contamination in relation to land, water or a site as having a substance present in or on that land, water or site at above background concentrations that presents, or has the potential to present, a risk of harm to human health, the environment or any environmental value.

A site is therefore said to be contaminated if it has a substance in it at above background concentrations, which presents or has the potential to present a risk of harm to human health or the environment. The environment includes living things and their physical and biological surroundings, and interactions between these.

Environmental remediation of contaminated sites is applied in two ways:

1. by applying actions to the contamination site itself. This can lead to fixation, immobilization, microencapsulation, solidification or removal of the actual source of pollution, for example by means of decontaminating the polluted areas or surfaces, and
2. evaluating risks related to pollution exposure to people and thinking of ways of breaking the pathways between the pollution source and people. This approach might lead to evacuation, area isolation or changing land use and the local populations living habits.

The two ways mentioned above are complementary. When deciding on the actual remediation work, several different factors need to be taken into account. As every site has its own characteristics, there is no simple quick fix. The most important thing is to understand that remediation actions need to be justified and optimized—the adopted actions must do more good than harm. For example, increased pollution levels do not necessarily mean that the increase is harmful; some living environments are within the internationally accepted levels. Thus, evacuating or isolating areas without firm scientific grounds for it can needlessly cause distress to the people it concerns.

1.3 Examples of World's Worst Environmental Disasters

Our environment has been the victim of all sorts of attacks. Some of these attacks are natural, such as hurricane Katrina in the United States in 2005, the Valdivia Earthquake in Chile in 1960 or Lake Nyos limnic CO_2 deadly eruption in Cameroon, West Africa in 1986. However, there are attacks that are unnatural and man-made, such as wars, (e.g., 1st and 2nd World wars) explosions (e.g., Chernobyl explosion in Ukraine, former Soviet Union in 1986), chemical or oil spill disasters (e.g., 1989 Exxon valdez and 2010 BP Macondo oil spill disaster in the United States). These attacks usually carry with them heavy price tags as communities, biodiversity, and eco-systems are damaged beyond full compensation and repair.

The exploitation of natural resources has not always been without some ecological side effects. The protection of local communities and biodiversity, indigenous populations and ecosystems, the reduction of emissions to air and water, land reclamation, waste management, and avoidance of oil spills are all important during resource exploration and production operations. Access to new exploration areas often depends upon the perception by foreign governments and communities that companies have made a commitment to good environmental practices.

In addition to chemical pollution by hydrocarbons, there are other environmental concerns linked with oil industry operations. These range from clearance of land for oilfield facilities, hydrological changes due to construction of roads and pipelines, and contamination from chemicals other than hydrocarbons.

Four examples of world's worst environmental disasters with disastrous environmental effect, which have drawn public attention are discussed below.

1.3.1 The BP Macondo Oil Well Disaster in 2010

The attention of the world was drawn to the unprecedented oil spill in the Gulf of Mexico that took place on the 20th of April, 2010. On this day, the British Petroleum (BP) Deep water Horizon oil rig in the Gulf of Mexico blew up, killing 11 workers and injuring 17 others (Welch and Joyner 2010), affected and killed huge populations of marine animals, soiled 510 Km of beaches and shorelines (Bowermaster 2010). Hydrocarbons continued to flow from the reservoir through the wellbore and the blowout preventer (BOP) for 87 days, causing a massive offshore oil spill. Much as 24,000 barrels/day (nearly 5 million barrels of crude oil) was spilled and the damage was estimated to cost more than $24 billion (Robertson and Kraus 2010). The environmental impact of the Macondo oil well disaster was the focus of considerable media attention. The 2010 BP rig blowout in the Gulf of Mexico was considered by Robertson and Kraus (2010) as the world worst oil spill on marine water ever.

Top officials of BP initially did all they could do to minimize the damage, or at least the public relations damage. Their initial estimate of the amount of oil being spilled was an even 1000 barrels per day—a quantity that led BP's CEO, Tony Harward, to note that "the Gulf of Mexico is a very big ocean, and the volume of oil we are putting into it is tiny in relation to the total volume of water" (Freudenburg and Gramling 2011). It didn't take long for BP's CEO to swallow his pride and accept the colossal damage the oil well disaster had caused the environment and biodiversity when faced with undeniable facts and public outrage. Figure 1.4 is a clear evidence of the colossal damage.

The loss of the containment was caused by a blowout during drilling of a deep-water well with key outcomes that included:

- failure to recognise that primary barrier integrity was compromised;
- failure to conduct appropriate tests on controls in place;
- poor design and failure of the blowout preventer;
- lack of control of ignition sources.

Admittedly, responsible actors in the petroleum sectors (e.g., BP, Chevron and Texaco) are trying to enhance their performance by introducing effective environmental policy and processes; including risk assessment and environmental management systems, and by employment of advanced technical solutions. In order to counteract the negative image of these sectors and to improve public perception the answer is to implement coherent environmental project management systems in their decision-making process.

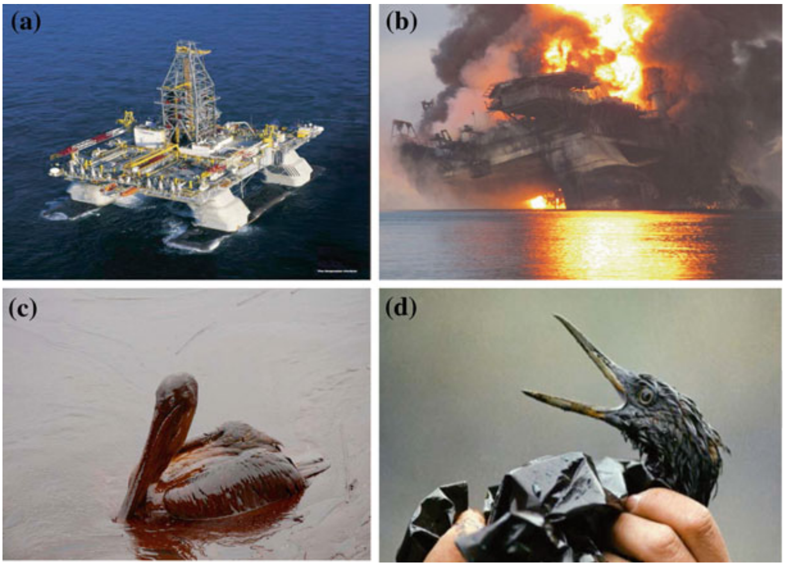

Fig. 1.4 Macondo oil well disaster and its impact on biodiversity. **a** Deepwater Horizon prior to explosion. **b** Deepwater Horizon after explosion. **c** An oil-stained Brown Pelican near Grande Isle, Louisiana, photo care of Governor Bobby Jindal. **d** An oil soaked bird is examined on an island in Prince William Sound, Alaska, April 1989 AP Photo/Jack Smith

1.3.2 *PTTEPA Montara Gas Well Disaster in 2009*

The Montara oil spill was an oil and gas leak and subsequent slick that took place in the Montara oil field in the Timor Sea, off the northern coast of Western Australia. It is considered one of the Australias worst oil disasters. The slick was released following a blowout from the Montara wellhead platform on August 21, 2009, and continued leaking until November 3, 2009 (in total of 74 days), when the leak was stopped by pumping mud into the well and the wellbore cemented thus "capping" the blowout. The Montara incident was estimated to have spilled approximately 30,000 barrels of light sweet crude oil during the 74 day incident (21 August–3 November 2009).

Just as BP Macondo oil disaster was considered the worst environmental disaster America has ever faced, the Montara gas well disaster was considered the worst in the history of Australia (Deep Water Report 2011). The 2010 BP Macondo oil well disaster in the Gulf of Mexico and 2009 PTTEPAA Montara gas well disaster in the Timor Sea are two good examples of what could go wrong when appropriate project management procedures and processes are not implemented in the environmental management systems (Fig. 1.5).

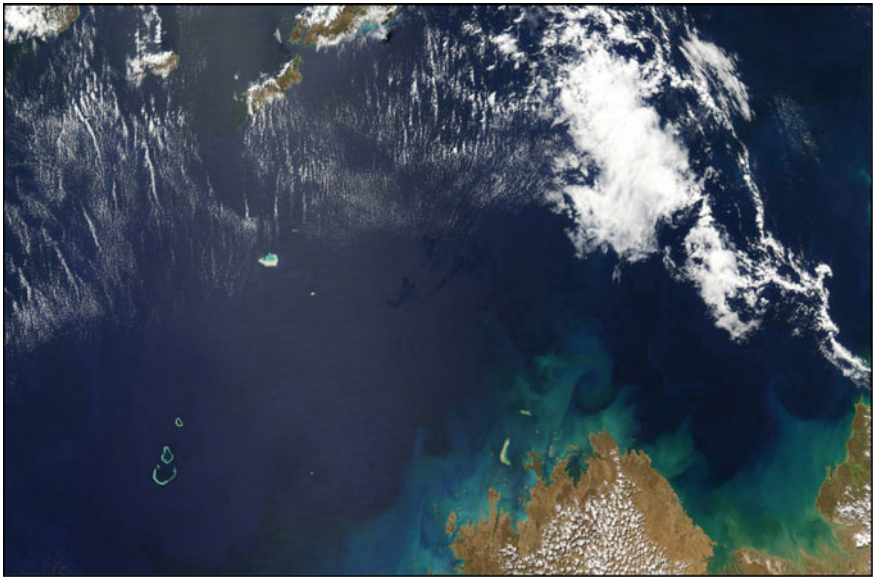

Fig. 1.5 Satellite image of an oil and gas slick in the Timor Sea, off the norther coast of Western Australia (*Source* http://eoimages.gsfc.nasa.gov/images/imagerecords/40000/40254/timorsea_tmo_2009260_1.jpg)

Fig. 1.6 The catastrophic environmental effect of CO_2 gas eruption at Lake Nyos in Cameroon, West Africa. **a** Animals around Lake Nyos before environmental disaster. **b** Animals killed by Lake Nyos gasses. **c** Lake Nyos before environmental disaster. **d** Lake Nyos as it appeared less than two weeks after the eruption in August 29, 1986

1.3.3 Exxon Valdez Oil Spill Disaster 1989

The supertanker Valdez, operated by US organization Exxon Group, ran around in March 1989 on a reef in Prince William Sound, Alaska due to human error. It spilled 11 million gallons of crude oil and caused one of the largest man-made ecological disasters. The oil slick covered 3000 square miles. While a clean-up plan outlined how an oil spill would be handled, including provisions for maintaining equipment (such as a containment boom) and a response team to be on 24 h notice, a spill of this size had not been anticipated. To make matters worse, time was wasted as corporations, the Alaskan state government and the national government argued over who should take control of the situation, who would pay for what and who was responsible. The impact of the oil spill on the ocean habitat is shown, e.g., in Fig. 1.4d.

1.3.4 Lake Nyos Limnic Eruption in 1986

How would it be like if you'd see all the living beings around you drop dead, all the way from insects to humans? What's that feeling you get when, without a warning, everything collapses around you and you've got no idea why?

The natural disaster that took place at Lake Nyos, a volcanic crater lake in Cameroon, West Africa on the 21st of August, 1986, attest to carbon dioxide as one of the most dangerous among the greenhouse gas emissions. "Limnic" refers to bodies of freshwater, like lakes and rivers. A limnic eruption occurs when gas bubbles up from the bottom of a lake and, unlike volcanic eruption, leaves little evidence and doesn't last for very long.

The lake is 208 m deep and is one of the three known lakes that are saturated with carbon dioxide (see, e.g., Baker 2014). On the 21st of August, 1986, at approximately 9.30 p.m., the Lake suddenly released into the atmosphere 80 million cubic metres of CO_2. The deadly gas spilled over the lake into two valleys. Being denser than air, CO_2 settled down and spread in a thick layer, displacing breathable air upwards. The environmental effect reached as far as twenty to twenty-five kilometers from the lake, suffocating wildwife, livestock, and humans, killing nearly 2000 people and 3,500 livestock (see e.g., Krajick 2003; New York Times 2001 and Fig. 1.6).

What would cause Lake Nyos to emit this huge, suffocating cloud of CO_2? Although, the answer may never be known for certain, many scientists (e.g., Kling et al. 1987) believe that the lake suddenly "turned over", bringing to the surface water that contained huge quantities of dissolved carbon dioxide. One theory is that a small confined area of the lake released gas allowing for the stratification in Lake Nyos to remain (Kanari 1989). Another theory describes a slow influx of heat into the system causing instability (Kling et al. 1987). Whatever the theory, the event resulted in the rapid mixing of the supersaturated deep water with the upper layers of the lake, where the reduced pressure allowed the stored CO_2 to effervesce out of solution.

1.4 Lessons Learned

Many of world's environmental disasters could have been avoided if the responsible operators and their project management group had recognized the importance of ethics, communication and teamwork among the engineers, designers, constructors, and managers of projects especially during the planning phase. This basic need relates directly to projects in all sectors in general, not only environmental projects.

Another lesson is the need for a detailed checklist of questions to be prepared by the project sponsor or their representative, prior to commencing the feasibility studies. The checklist would ensure proper attention to the feasibility studies, which in turn becomes the basis for preliminary designs, technical and environmental alternatives, and subsequent tasks in the environmental project management system. There is the need to establish and enforce standards to ensure public health, worker safety, and environmental protection are safeguarded. This will require an integrated planning, monitoring and control system to develop the guidelines and use the detailed checklists to ensure these standards are being met.

Finally, there is need for detailed feasibility studies, which serve a multitude of purposes ranging from preliminary design refinement (for cost estimates and manpower/equipment needs) to development of necessary baseline data for ongoing evaluation of subsequent tasks and environmental impact assessment. It is clear that such detailed information would have avoided the majority of the problems identified in the examples above.

Unfortunately, the oil companies did not learn from their mistakes in planning, design, and construction of the oil rig system (see e.g., Polson 2011). This becomes apparent in the operation of the system. Table 1.1 shows six major oil spill incident, their locations, estimated volume of oil spilled and corresponding environmental effects. The four examples narrated above is a proof that there is need for paradigm shift in the way our natural environment is monitored, conserved, remediated and protected.

1.5 Concluding Remarks

This introductory chapter discusses the need to conserve, preserve and protect the environment, or as the Bible puts it: *"to till and keep the earth"*, see *Gen. 2:15* (Bible 2014). This is the core principle of sustainable development; a development aimed to "meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Four examples of world's worst environmental disasters were evaluated to determine the level of disaster caused and lesson learned from the aftermath of these disasters. In this chapter, an attempt was made to distinguish between an environment, a project and project management as a prelude for defining the concept of environmental project management.

References

AIPM (1996) National Competency Standards for Project Management. Australian Institute for Project Management, Sydney, Australia

Aluko MA (2001) Sustainable development, environmental degradation and the entrenchment of poverty in the Niger Delta of Nigeria. J Hum Ecol 15(1):63–68

APM (2012) Project management body of knowledge. 6th edn. Dixon M (ed) Association for Project Management, High Wycombe, UK

Baccarini D (1999) The logical framework method for defining project success. Proj Manag J 30(4):25–32

Badiru AB (2008) Industrial project management: concepts, tools and techniques

Badiru AB, Osisanya SO (2013) Project management for the oil and gas industry : a world system approach. Taylor and Francis Group LLC

Baker K (2014) The worst world disasters of all time, www.eBookit.com, 198 p

Barr N, Cary J (1992) Greening a brown land. Macmillan, Melbourne

Bible (2014) King James Version. www.kingjamesbibleonline.org. Accessed 5 May 2014

Bowman RR (1967) An analysis of Project Management Concepts in the Missle/space Industry, MBA Thesis, Utah State University

Bowermaster J (2010) Bowermaster's adventures - measuring the extent of oil spillage. www.Garling.com. Accessed 19 July 2013

Boyes S, Elliott M, (2010) Oil spill case study-amoco cadiz. http://www.chemgapedia.de/vsengine/vlu/vsc/en/ch/16/uc/vlus/amococadizoilspill.vlu.html. (Accessed 17 Jul 2014)

Brown L, staff of the Worldwatch Institute (1987, 1988, 1989, 1990, 1991, 1992, 1993) State of the World. Norton, New York
Bucknall J, Hamilton K, Kishor N, Kraus C, Pillai P (2000) Environment, in sourcebook for PRSPs (draft). World Bank, Washington, DC
Cappo M, Alongi DM, Williams D, Duke N (1995) A review and synthesis of Australian Fisheries Habitat Research: major threats, issues and gaps in knowledge of coastal and marine fisheries habitats. Fisheries Research and Development Corporation. http://www.aims.gov.au/pages/research/afhr/afhr-00.html
Chapman RL (1973) Project management in NASA: the system and the men, Washington: Scientific and Technical Information Office, National Aeronautics and Space Administration; for sale by the Superintendent of Documents. Government Printing Office, U.S
Cleveland CJ, Hogan CM, Saundry P (2010) Deepwater horizon oil spill. In: Encyclopedia of Earth. http://www.eoearth.org/article/Deepwater_Horizon_oil_spill. (Accessed 23 Jul 2014)
Cohen D (1998) Voluntary codes: the role of the canadian state in a privatised regulatory environment. In: Cohen D, Webb K (eds) A draft paper presented at the voluntary codes symposium, Office of Consumer Affairs, Industry Canada and Regulatory Affairs, Treasury Board, Ottawa, September 1996, included in Exploring Voluntary Codes in the Marketplace. Government of Canada, Ottawa
Cookie-Davies T (2002) The "real" success factors on projects. Int J Proj Manag 20(185):190
Cutler J, Cleveland CJ, Saundry P (2010) Exxon Valdez oil spill. In: Encyclopedia of Earth. http://www.eoearth.org/article/Exxon_Valdez_oil_spill. (Accessed 23 Jul 2010)
Deep Water Report (2011) The Gulf of oil disaster and the future of offshore drilling: report to the president, January 2011: National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, US Government Printing Office, 24 May 2011, Washington DC, USA
Dincer I, Midilli A, Herbasli A, Karakoc TH (2009) Global warming: engineering solutions, Springer Science & Business Media, 685 p
Dinsmore PC, Cabanis-Brewin J (2006) The AMA handbook of project management. American Management Association, New York
Enzler SM (2006) Environmental Disasters (Top 10 of Anthropogenic and Natural Environmental Disasters). September 2006. http://www.lenntech.com/environmental-disasters.htm
Fisher DF (2003) Australian environmental law. Lawbook Co., Australia, New South Wales, Pyrmont
Fisher DF (2014) Australian environmental law: norms, principles and rules. Thomson Reuters Australia Limited, 729 p
Freudenburg WR, Gramling R (2011) The BP oil spill disaster and the future of energy in America. MIT Press, Cambridge
Gordon S (2003) Regulatory design for water quality management in perth, western australia: economic instruments series: Paper 2: innovative economic instruments for nonpoint source water pollution in the swan-canning river system. School of Resoruces, Environment and Society, The Australian National University, p 11
Government of Western Australia (1986) Environmental Protection Act 1986. www.slp.wa.gov.au/legislation/agency.nsf/dec.menu.htmlx. 16 June 2014
Gunningham N, Grabosky P (1998) Smart Regulation: Designing Environmental Policy, Chapter 2. Oxford University Press, Oxford, pp 37–91
Gunningham N, Sinclair D (2004) Non-point pollution, voluntarism and policy failure: lessons for the swan-canning. Environ Plan Law J 21:93–104
Harrison K, Antweiler W (2003) Incentives for pollution abatement: regulation, regulatory threats, and non-governmental pressures, 22 J Policy Anal Manag 3:361–382
Havranek TJ (1999) Modern project management techniques for the environmental remediation industry. St. Lucie Press, Washington, DC
Heap J (1986) The Antarctic treaty system: environmental protection, conservation and the question of competing us

Intergovernmental Panel on Climate Change (IPCC). Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis, Summary for Policymakers. http://www.climatechange2013.org. Accessed 08 Feb 2014

International Project Management Association IPMA, 2006. ICB-IPMB competence baseline, version 3.0. http://users.ntua.gr/jpp/icb3.pdf/2012

Johnson DL, Ambrose SH, Bassett TJ, Bowen ML, Crummey DE, Isaacson JS, Johnson DN, Lamb P, Saul M, Winter-Nelson AE (1997) Meanings of environmental terms. J Environ Qual 1997(26):581–589. doi:10.2134/jeq1997.00472425002600030002x

Kanari S (1989) An inference on process of gas outburst from lake Nyos, Cameroon. J Volcanol Geotherm Res 39(135):149

Khatib H (2003) Economic evaluation of projects in electricity supply industry. Institution of Engineering and Technology, London

Kling GW, Clark MA, Compton HR, Devine JD, Evans WC, Humphrey AM, Koenigsberg EJ, Lockwood JP, Tuttle ML, Wagner GN (1987) The 1986 Lake Nyos gas disaster in Cameroon. West-Africa. Sci 236(169):175

Kerzner H (2010) Project management: systems approach to planning, scheduling, and controlling. Wiley, Hoboken

Krajick K (2003) Defusing Africa's killer lakes" (PDF). Smithsonian 34(6):46–50. Archived from the original (PDF) on 4 April 2005. Accessed 15 Dec 2014

Lewis JP (2000) The project manager's desk reference: a comprehensive guide to project planning, scheduling, evaluation, and systems. McGraw-Hill, New York

Li L, Wei Y, Fei C (2007) Relation of the project manager leadership and performance. IEEE, pp 5244–5247

Liu JG, Diamond J (2005) China's environment in a globalizing world. Nature 435(7046):1179–1186

Macintosh A, Hamilton C (2008) Human Ecology: Environmental protection and ecology, In: Jorgensen S, Fath B (eds) Encyclopedia of Ecology, Elsevier, Amsterdam, pp. 1342–1350

Magnani E (2011) Environmental protection inequality, and institutional change. J Ecol Econ Rev, Ann New York Acad Sci 1219:197–208

Mungo BB (1967) Management studies in the field of aeronautics: management of projects, J R Aeronaut Soc 71:334–36; 336–38

Munns AK, Bjeirmi BF (1996) The role of project management in achieving project success. Int J Proj Manag 14(2):81–87

Neefjes K (2000) Environments and livelihoods: strategies for sustainability. Oxfam, Oxford

Newman P, Beatley T, Boyer H (2009) Resilient cities: responding to peak oil and climate change. Island Press, 184 p

New York Times (2001) Trying to tame the roar of deadly lakes, 27 Feb 2001. Accessed 9 Dec 2014

Nicholas JM (2004) Project management for business and engineering. Elsevier, Burlington

Nunan F, Grant U, Bahiigwa G, Muramira T, Bajracharya P, Pritchard D, Vargas MJ (2002) A study of poverty-environment indicators with case studies from Nepal. Nicaragua and Uganda. Environment Policy Department Issue Paper No 2

Obama B (2014) Speech delivered by the President of the United States of America, Barack Obama, at the 2014 Climate Summit at the United Nations Headquarters in New York. http://insideclimatenews.org. Accessed 1 Sept 2014

OECD (2008) OECD sustainable development studies measuring sustainable production, OECD Publishing

Othieno H, Awange J (2016) Energy resources in Africa: distribution, opportunities and challenges. Springer International Publications

Paltridge GW (2010) The climate caper: facts and fallacies of global warming. Taylor Trade Publications, Lanham

PMI (2013) A guide to the project management body of knowledge, PMBoK guide, 5h edn. Project Management Institute Inc., Atlanta, Newtown Square

PMI (2015) PMI Today. A supplement to PM Network published by Project Management Institute, vol 29, no. 7

Polson J (2011) BP oil still ashore one year after end of Gulf spill. Bloomberg. http://www.bloomber.com/news/2011-07-15/bp-oil-still-washing-ashore-one-year-after-end-of-gulf-spill.html. Accessed 25 July 2013

Robertson C, Kraus C (2010) Gulf spill is the largest of its kind; scientists say. New York Times. Accessed 22 July 2013

Rosenthal E (2007) U.N. Chief Seeks More Climate Change Leadership, New York Times, 18 November 2007

Salazar-Aramayo JL et al (2013) A conceptual model for project management of exploration and production in the oil and gas industry: the case of a Brazilian company. Int J Proj Manag 31:589–601

Smith NJ (2002) Engineering project management, 2nd edn. Blackwell

Turner JR (ed) (2009) The handbook of project-based management: Leading strategic change in organizations, 3rd edn. McGraw-Hill, New York

United Nations (1992) Agenda 21. Conference document from the UN Conference on Environment and Development, Rio de Janero

WCED (1987) World commission on environment and development: our common future (the Brundtland report). Oxford University Press, Oxford

Welch W, Joyner C (2010) Memorial services honors 11 dead oil rig workers, USA today. http://usatoday.com/news/nation/2010-05-oil-spill-victims-memorial.N.htm. Accessed 19 July 2013

Westland J (2006) The project management life cycle: a complete step by step methodology for iniating, planning. Executing & closing a project successfully. Kogan Page Limited, London

Yale (2006) Pilot 2006 environmental performance index. Yale Centre for Environmental Law and Policy, Yale University

Zedillo E (2008) Global warming: looking beyond Kyoto, Brookings Institution Press, 237 p

Zhang K, Wen Z (2008) Review and challenges of policies of environmental protection and sustainable development in China. J Environ Manag 88(4):1249–1261

Chapter 2
The Need for Environmental Project Management

Having defined in Chap. 1, 'environment' as the components of the ecosystems (land, water, and air, including all layers of the atmosphere) to be effectively managed, and discussed the concept of project management as a set of tools and templates required to make this possible, an attempt will now be made to define environmental project management as a new paradigm shift in achieving the goal of sustainable development.

2.1 Environmental Project Management—An Overview

Before examining the specifics of environmental project management, it is worth spending a little time to elaborate on what is meant by an environmental-based project, as distinguished from 'green' project (see Fig. 2.1). This is done in the next section.

2.1.1 Environmental-Based Project: A Definition

To distinguish between a 'green' project, e.g., managing a road construction project in such a manner that the wetlands are least disturbed, and an environmental-based project, it is essential, first and foremost, to define what is meant by environmental-based project.

In its early stages, project of any kind is a *temporary endeavor* undertaken to initiate and manage. Later, it evolves and becomes part of the routine operation in the organization. Although environmental-based project shares some common ground with other 'green' projects that are embedded with environmental aspects (e.g., road construction project, oil and gas project, research and development (R&D)

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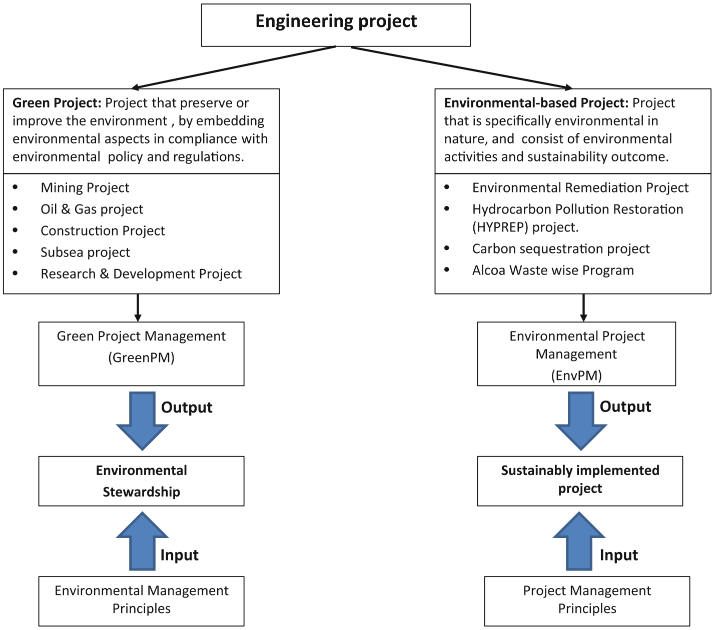

Fig. 2.1 Green project versus environmental-based project

project and mining project), its core difference lies on the fact that it comprises of environmental activities, which are combined together to achieve a sustainable objective of reducing the negative environmental impacts (e.g., oil spills, greenhouse gas emissions, groundwater contamination, etc.). Consequently, it can be said that environmental-based projects are first and foremost environmental in nature. A good example is the Nigeria's hydrocarbon pollution restoration project (HYPREP), whose main objective was to remediate the environment and restore the coastal wetlands.

An environmental-based project has some key characteristics which distinguishes it from other projects. The most obvious characteristic is that environmental-based project has to achieve a specific environmental objective, e.g. *"to cut greenhouse gas emission or reduce industrial waste by 20 % by the year 2020."* Such an undertaking has some key characteristics which signal that it is a project and not a routine activity that is part of the organization's normal business. As the environmental-based project becomes embedded in the management structure of the organization, it will become a routine operation and part of day-to-day environmental management activity.

2.1.2 *Environmental-Based Project Versus Business Operations*

Projects and operations complement one another so that an organisation can continually achieve their goals and objectives (see Table 2.1).

Table 2.1 Environmental-based project versus business operations

Environmental-based project	Business operations
• New process, product or system	• Repeat process, product or system
• Has one environmental goal	• Has several goals
• Has a start and finish dates	• Ongoing
• Has a sustainable outcome	• Several outcomes
• Systems are created to integrate efforts, e.g., EMS	• Well-established systems in place to integrate efforts
• Greater uncertainty of performance, cost and schedule	• Greater certainty of performance, cost and schedule
• Outside of the organisation	• Part of line organization
• It implies change	• Implies business as usual

Operational tasks sustain the business and frequently generate income while projects have a specific objective and may only have costs. An outcome or result of a project can become a part of operations upon completion. Operations includes tasks that are repeatable, cyclical, and ongoing, while projects have a defined start and end date, temporary, and provide a unique product, result or service (Burford 2012).

In the environmental industry, with informal processes and controls, and where staff work on business, project and operational tasks concurrently, intermixing business, project and operational tasks can easily occur. The business cycle is a preproject stage during which business opportunities are explored. The environmental project cycle covers the project execution through different environmental project management phases, while the operation cycle covers the use of the project results and represents the benefit stage. The difference between an environmental project cycle and operation cycle, and the effects of an environmental-based project and its output on usual business operations as an ongoing needs of the environment for sustainability is illustrated in Fig. 2.2.

2.1.3 Examples of Environmental-Based Projects in Australia

Projects can be large or small and involve one person, group or thousands of people. They can be done in one week, a month, or take years to complete. Environmental-based projects involve using knowledge, skills, and innovative technology to create a sustainable change in product, service, result or system. Examples of environmental-based projects across Australia include the following:

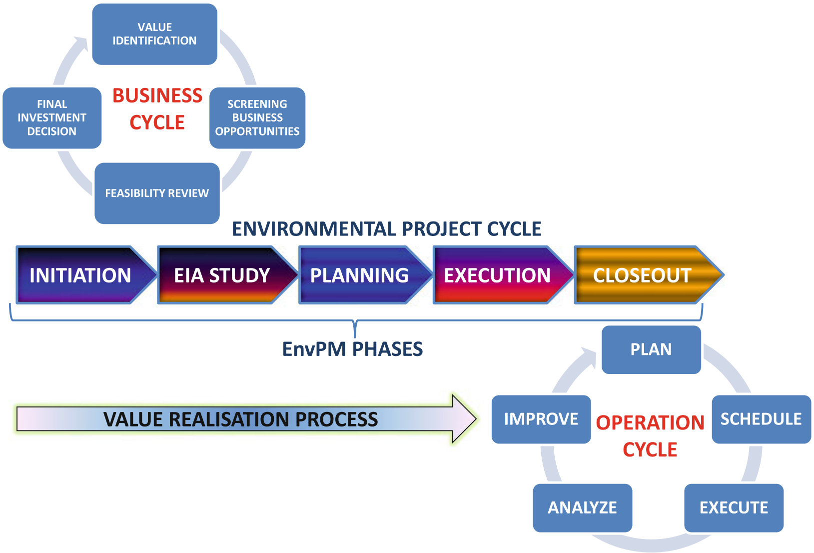

Fig. 2.2 Environmental project cycle in the value realisation process

- Ten Million Trees program: Alcoa's response to global climate change. The key objective is to plant ten million new trees by 2020. It is expected that the ten million new trees will absorb more than 250,000 metric tonnes of carbon dioxide per year during their lifetime (Alcoa 2014).
- CO_2 Reduction Program: A focused effort to reduce anode effects at the Portland aluminium smelter in Australia, which resulted in an 83 %, or 106,000 tonnes reduction of carbon dioxide equivalent emissions annually and US$135,000 in maintenance savings each year (Alcoa 2014).
- Carbon Capture Project: The Kwinana residue carbon capture plant in Western Australia currently sequester almost 70,000 tonnes of CO_2 a year that would normally be released to the atmosphere—that is the equivalent of taking 17,500 cars off the road (Alcoa 2014).
- Alcoa Darling Range Water Catchment Program: Salinity and intermediate rainfall zone mining was designed to protect the quality of water supply catchments in Western Australia (Alcoa 2014).
- Alcoa Wastewise Program: A practical and step-by-step approach to minimizing waste and maximizing the efficient use of valuable resources (Alcoa 2014).

In 2007, Alcoa of Australia was the first corporation to register and formally report to the Federal Department of Industry, Tourism and Resources (DITR) on the implementation of the Energy Efficiency Opportunities (EEO) Act 2007 and Greenhouse Challenge Plus programs. With water management being one of Australia's most critical issues, Alcoa of Australia invested $600,000 in a three year partnership with Murdoch University to establish the Alcoa Chair in Sustainable Water Management in late 2008 (Alcoa 2014).

A key achievement in emissions reduction was seen at Portland Aluminium in 2009. The Carbon Bakes Sustainability Project was implemented in 2008, with full commissioning at the end of quarter one in 2009. This included an 80 % reduction in Polycyclic Aromatic Hydrocarbon (PAHs) emissions from the anode baking process, and a more than 90 % reduction in volatile organic compounds (Alcoa 2014).

Apart from Alcoa, Woodside Petroleum also invested AUS$100 million in a program with CO_2 Australia to offset carbon emissions from the Pluto reservoir. This investment creates Australia's biggest commercial emissions offset program based on dedicated forest carbon sink planting. The plantings took place over a five year period, which commenced in 2008 (Woodside 2014).

In part IV (Chaps. 18 and 19), case studies of environmental projects from conceptualization to delivery, both in developed and developing countries, are reviewed to demonstrate the approaches to reducing environmental effects in terms of waste reuse and pollution restoration. From the examples provided and case studies reviewed, it can be seen that a wide variety of projects are used by different companies only to demonstrate their *environmental stewardship* or *compliance*, but without proper implementation of environmental project management methodology.

2.1.4 Definition of Environmental Project Management

"No problem can be solved from the same consciousness that created it—A. Einstein"

Environmental project management (EnvPM) is a relatively new term that can have different interpretations. Most people, when asked, would probably say it means just what it says—managing the environment as a project. The fine details of how this is done are of little interest to them. However, to the people working in the field, the term may cover the principles, knowledge areas, the processes, the detailed tools and techniques used to manage specific element of the environment, such as water, air, land and the living organisms. Or they may associate the term with the environmental management systems and processes that are used to guide potential impact of project activities on the environment.

EnvPM should not be confused with green project management (GreenPM)—a term coined by Maltzman and Shirley (2012) and Mochal and Krasnoff (2010) with a goal of incorporating an organization's environmental policies into project management processes (see e.g., Fig. 2.1). Green project management is a model designed for project managers to think 'green' throughout the life of a project, and when making decisions that take into account the impact of human activities on the environment.

Environmental project management, on the other hand, is a concept that uses project management principles, methods and processes, to manage and improve an element of the ecosystem, e.g., water, air, plants, land or living organisms, in order to achieve a sustainable outcome (see e.g., Fig. 5.1, p. 97).

The concept can be illustrated as follows:

EnvPM = Environment + Project + Management

EnvPM = Ecosystem—the biological and physical elements of our life
(e.g., water, air, plants, land, and living organisms)
+ a temporary and unique endeavor undertaken to create a sustainable change
+ organizing, coordinating, and controlling an element of the ecosystem.

Environmental project management is a paradigm shift in the way environment should be managed and improved. Thomas (2005) puts it very bluntly when he said:

> *"humans cannot continue to exploit the environment for resources and as a sink for our wastes, and leave a diverse and vibrant environment for the future generations. Even now, given the way we are drawing down resources (e.g., fossil fuels), diminishing biodiversity, and adding unwanted chemicals to our air and water, serious problems may face current generation. We cannot continue on a 'business as usual' plan as in the past. We must take action".*

It is imperative that we, as people, must protect or conserve the environment; and in the alternative, remediate the contaminated sites.

The following definitions of project, project management, and environmental management are useful in developing an environmental project management framework:

1. A project is "a unique endeavor to produce a set of deliverables, in which human, material and financial resources are organized in a novel way, to undertake a unique scope of work, of given specification, within clearly specified time, cost and quality constraints" (Turner 2009; Westland 2006).
2. Project management is the "art and science of planning, organizing, integrating, directing, and controlling all committed resources—throughout the life of a project—to achieve the predetermined objectives of scope, quality, time, cost, and customer satisfaction" (Havranek 1999).
3. Environmental management is the "process of allocating natural and artificial resources so as to make optimum use of the environment in satisfying basic human needs at the minimum, and more if possible, on a sustainable basis" (Jolly 1978).

The definitions provided above raise three important aspects—*time, cost, and quality*—which need to be considered in the establishment of any project, and are particularly pertinent in terms of the development of an environmental project management framework. These three aspects are often called the triple constraints of project management. Throughout the management of the project activities, the relationships between time, cost and quality must be regularly reviewed and trade-offs applied, when necessary to justify priority preference of one constraint over the other. For example, changes to one of the areas (e.g., halving the schedule to produce an environmental impact statement for an environmental project may well save on costs by reducing staff time, but result in poor quality of producing an incomplete environmental impact study).

The third definition, environmental management, is an attempt to integrate project management, environmental management and sustainable development. In addition to delivering projects in accordance with customer satisfaction, as stated in the above definition of project management, environmental project must be performed in accordance with environmental regulatory requirements of the country where the project is being executed. Furthermore, an environmental project must be performed in conformance with the appropriate health, safety and environmental laws, policy and standards to which a particular organization subscribes (in particular, those outlined in AS/NZ 14001, AS/NZ 4801 and BS OHSAS 18001). Finally, an environmental project undertaking must incorporate the sustainability principles, which is "meeting our current needs without compromising the ability of future generations to meet their needs", that is, the need of sound environment, just society and healthy economy (WCED 1987).

2.1.5 Significance of Environmental Project Management

The advancement of science and technology has mixed blessings. It brought about many benefits to the society but, at the same time, new problems in the disposal and handling of toxic industrial waste, green house gas emissions, underground water, nuclear waste and debris from space has added to the list of environmental pollutants. Every nation has now become aware of the impact of heavy and large scale industrialization on the precious environment in which we have to breathe and live. To safeguard against environmental damage, all nations of the world are enforcing strict environmental laws and regulations on resource exploration and production industries—both in the public and private sectors. However, due to lack of proper surveillance and dishonest practices, a vital aspect of the environment, which could ultimately threaten our very existence is being given the go-by. It has rightly been said that '*we have not inherited the world from our ancestors but have borrowed it from our descendants*', and it is our responsibility to ensure that we leave it for them to live in.

In this fast-changing, technology-driven world, any new project proposal must first consider the impact of the project on the environment. The additional costs, time and performance required for adherence to the norms and stipulations of the concerned environmental authorities must be built into the cost and schedule structure of the project.

It is important that environmental strategic programs are integrated into business planning and decisions related to environmental protection, conservation and remediation. Projects should be screened to determine the need for an environmental impact assessment, using various monitoring tools such as remote sensing, geographical information system (GIS), global navigation satellite systems (GNSS), and photogrammetry, discussed in part III of the book, prior to initiating a project.

2.2 Scope and Objective of the Book

As society moves through the twenty-first century, it faces an important challenge: to protect and preserve the Earth's resources, while the society continues to develop economically. The rapid growth and advancement of science and technology that began in earnest with the industrial revolution have taken a toll on the natural environment. Failure to capture, measure, and report environmental project outcomes has cost Australia alone several billion of dollars a year in lost efficiency, repeated errors, and unexploited opportunities.

In order to "meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987), an integrated set of solutions that include expanding all natural resources, improving efficiency, and minimising environmental impact is required. The field of project management is evolving fast to adapt to the requirements of this new era. Emphasis is placed on critical issues such as greenhouse gas (GHG) emissions, global warming, climate change, groundwater contamination, oil spills, soil, water and air pollution.

Managing an environmental project comes with a unique set of challenges that include how to incorporate environmental impact perspective into project strategy. The challenges also include how to capture, measure, and manage *environmental, economic and social impacts* on project planning documents. Environmental project management addresses these issues for professionals in the private, public and the not-for-profit sectors. It shows them how to plan and track their environmental projects with the professionalism and discipline widely applied to other project investments.

The purpose of this book, therefore, is to both make generally accepted project management knowledge accessible to experts in the technical areas of environmental science and to help improve their performance through increased understanding and sound implementation of environmental project management methods and processes. The overall objective of the book is to introduce a systems approach that integrates environmental management, project management and geospatial techniques into project planning and decision-making processes. Geospatial awareness is essential for implementing and managing a broad portfolio of projects ranging from complex infrastructure projects to pollution abatement and waste management tasks. For effective decision-making, environmental managers require accurate geospatial information with a seamless dataflow.

Underpinning the specific issues associated with effective and efficient environmental impact assessment and monitoring, a proven environmental project management framework is developed to provide project management professionals with a disciplined and structured approach that can be used to analyse and critically evaluate management aspects of environmental projects.

Most projects that are termed "environmental projects" are in essence projects smoked-screened with the term "environment" in order to pass the legislative requirements of a given jurisdiction. This book clearly distinguishes between environmental project management (EnvPM) and green project management (GreenPM); and provides, for the first time, a close-knit amalgamation of environmental management and project management concepts, using geospatial methods to form an environmental project management concept. This is the key achievement of the book.

This book is divided into four parts. Part 1: setting for environmental project management, consists of two chapters; part 2: principles of environmental project management contains five chapters; part 3: essential tools and techniques for environmental project management includes ten chapters and finally, part 4: case studies on environmental conservation and remediation projects combines three chapters together to discuss the case study of environmental projects in Australia and challenges of applying environmental project management in developing countries.

The work will not make an expert of anyone in any of the subjects upon which it touches. It is intended as an overview to help the reader focus on the environmental issues that are relevant to green house gas emissions, oil spills, diminishing biodiversity, and industrial wastes. The complete work can be used as a handbook for professionals in the private, public and not-for-profit sectors, a valuable resource for students at both undergraduate and Masters levels and an indispensable guide for anyone who wants to develop their skills in modern project management, environmental management and geospatials.

The book is written with an intention to raise the bar on the professionalism with which environmental projects are planned, monitored and measured. It should be understood that this book is not written only for environmental project managers; it provides useful information for any person wishing to enhance their knowledge on project management principles, methods and processes. It is our hope that by reading this book, the reader will have a clearer and firmer grasp of the scope and seriousness of the environmental impact of human and industrial activities on planet, economy, and people.

2.3 Concluding Remarks

With increasing awareness about the need to protect and conserve nature, environmental issue, such as climate change, ozone depletion, loss of biodiversity, natural resource scarcity, and air pollution, is increasingly gaining importance. However, even after the existence of a large number of interdisciplinary courses such as environmental law and policy, environmental management and governance, sustainability and sustainable development, much more is needed to be done to make the subject applied. This chapter explained environmental project management as a key development factor that has a huge capacity to enhance social values, achieve technological advancement and improve economic prosperity without devastating the planet. Success in this field depends largely on one's interests and love towards nature and its awe inspiring processes. Those with an interest in social equity and an intense desire to protect and conserve resources for posterity would especially find this book very appealing.

References

Alcoa (2014) Environmental overview. www.alcoa.com. Accessed 16th Sept 2014

Burford LD (2012) Project management for flat organizations: cost effective steps to achieving successful results. J. Ross Publishing, Plantation

Havranek TJ (1999) Modern project management techniques for the environmental remediation industry. St. Lucie Press, Washington, DC

Jolly V (1978) The concept of environmental management development. Foram 8(2):13–26

Maltzman, R, Shirley D (2012) Green project management. CRC Press, Boca Raton, 296p

Mochal T, Krasnoff A (2010) Green project management: supporting ISO 14000 standard through project management process [electronic version]. http://greeneconomypost.com/green-project-management-greenpm-iso-14000-11040.htm. Accessed 14 Oct 2014

Thomas IG (2005) Environmental management processes and practices for Australia. Federation Press, Sydney, 360p

Turner JR (ed) (2009) The handbook of project-based management: Leading strategic change in organizations, 3rd edn. McGraw-Hill, New York

WCED (1987) World Commission on Environment and Development: our common future (the Brundtland report). Oxford University Press, Oxford

Westland J (2006) The project management life cycle: a complete step by step methodology for iniating, planning. Executing & closing a project successfully. Kogan Page Limited, London

Woodside (2014) Environmental case studies. http://www.woodside.com.au/Our-Approach/Sustainable-Development/Pages/Sustainable-Development-Report.aspx. Accessed 20 Sept 2014

Part II
Principles of Environmental Project Management

This part provides a background to the strategic aspects of environmental project management. It could be described as the "backbone" material of the book. Many of the scientific and practical "tools" used for making decisions involving accidental oil spillage, greenhouse gas emissions, industrial wastes and remediation are presented. Chapter 2 defines project management methodology starting with the principles of project management and then incorporating sustainability into project management framework. The latter chapters deal with the essential tools and techniques that are required for achieving sustainable project outcome and conclude with risk management approaches to environmental project management. Four main international standards have been used to develop a framework for environmental project management. These include the international standards organisation (ISO) 21500:2012 for guidance on project management, ISO 9001:2008 for quality management systems, ISO 14001:2004 for environmental management system, and ISO 31000:2009 for risk management.

Chapter 3
Environmental Project Management Methodology

> *Operations keeps the light on, strategy provides a light at the end of the tunnel, but project management is the train engine that moves the organisation forward*
>
> —Joy Gumz

Project management is a set of *tools* and *templates* designed to help the project management practitioner and to provide consistency of process. It is a methodology that defines the processes, responsibilities, and workflows needed to achieve an objective. Each project or initiative undertaken is unique in its constraints and issues. The information contained within the methodology should be adapted to a particular situation. Based on this premise, Project Management Body of Knowledge (PMBoK) and Projects IN Controlled Environment, version 2 (PRINCE 2) should not be considered as a methodology, but rather as a guide, which should be tailored to suit organisation's own internal project management methodology.

3.1 Principles of Project Management

Many of the most difficult engineering challenges of recent decades have been to design, develop, and implement new systems, types, and complexities never before attempted. Examples include the construction of oil drilling platforms in the North Sea off the coast of Great Britain, the development of the manned space program in both the United States and the former Soviet Union, and the worldwide installation of fibre optic lines for broadband telecommunications. The creation of these systems with performance capabilities not previously available, and within acceptable schedules and budgets has required the development of new methods of planning, organising, and controlling events. This is the essence of project management.

In the past, resource exploration and production (E&P) professionals were charged with the responsibility of exploring and producing hydrocarbon and other natural resources. However, the present challenge has gone beyond finding and developing barrels or molecules; they now must make complex decisions about managing

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technical performance, *environmental risks*, economies, and corporate resources. Decision are best made when projects are appropriately risked, consistently described in economic, technical, and environmental terms and assessed relative to how they interact through time with other investments to deliver value to the company. Merging environmental risk assessment and project management is a critical step.

An increasing number of professionals have been exposed to project management techniques as a result of several relatively recent influences. First, due to the mid-1980 personnel cutbacks and organisation changes, a variety of people have assumed project management roles as large projects developed during the subsequent years. Additionally, computer tools have made application of project management easier. Consequently, many relatively complex projects have benefited from the involvement of personnel familiar with project management.

Project managers who manage a single, small project can plan and schedule the project tasks without a formal planning and information system. However, when the project manager must manage several small projects or a large, complex project, a threshold is quickly reached in which the brain can no longer cope with the detail. The technical difference between project types are of great importance when selecting and applying project management techniques.

Modern project management in the "real world" has three competing interests. It has to think first on the stakeholders (people, organisations, community, etc.) for whom the solution is sought, estimate the optimum completion time (scheduling), then look for economically viable solutions (budgeting). However, the question of environmental stewardship, social responsibility, and economic prosperity cannot be ignored and that is becoming a serious global issue. All these competing interests must be satisfied for a project to proceed to execution.

Figure 3.1 illustrates various dimensions for application of project management in an environmental management system.

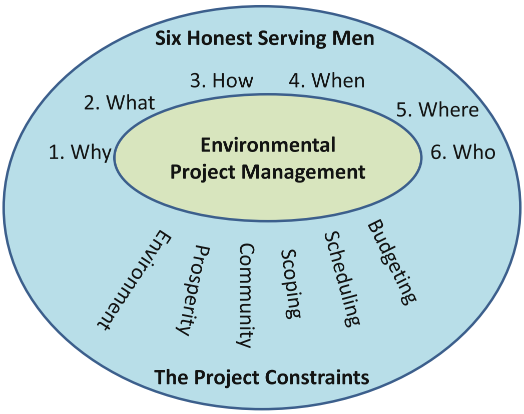

Fig. 3.1 Dimensions of environmental project management

The most important task in project management is scope planning. To ensure that project scoping is done right, it is a good idea to use Kipling's "six honest serving men" (Kipling 1902) to develop and continuously review the plan throughout the project life cycle.

An environmental project scope planning, using the principle of "six honest serving men" should aim to answer the following questions, arranged in strict chronological order of importance:

1. why are you doing a project? (definiteness of purpose, that is, the purpose, cause, or belief that inspires you to do what you do)
2. what are you going to do (creative vision with clearly defined objectives)?
3. how are you going to do it, i.e., how can you create change?, how do you want to change the status quo? (organised planning: the crystallization of vision into action using agreed strategy and tactics)
4. when will each step of the project happen? (budgeting time and money)
5. where will each part of the project take place?
6. who will execute each part of the project? (forming a "Mastermind" alliance/group; teamwork, using responsibility assignment matrix (RAM)).

The most important of the questions mentioned above is "Why". Project management is first and foremost about managing people and resources to achieve an established goals within parameters of cost, schedule, and quality (Boddy and Buchanan 1992). People or team members don't follow you because of what you do as a project manager/leader. They follow you because you believe in what you do and why you do it. Ability to address this question right lay a solid foundation for solution to the rest of the questions.

3.1.1 Project Management as a Process

> *"If you can't describe what you are doing as a process, you don't know what you're doing"—W. Edwards Deming.*

Project Management Institute's Body of Knowledge (PMBoK) defines a project management as "the application of knowledge, skills, tools and techniques to project activities to meet the project requirements." (PMI 2013). Management of a project follows a consistent series of steps that ensures it is successfully managed and meets the project's customer requirements. If the project management process is followed, it is assumed that the project will successfully meet its defined deliverables. A project management process, therefore, is a collection of tools and techniques that are used on a predefined set of inputs to produce a predefined set of outputs. The processes are interconnected and interdependent. Inputs to some are outputs of others. The full collection forms a methodology that supports all of the aspects of project management throughout a project life cycle from initiation of a new project to its completion or termination.

Project management is accomplished through application and integration of 47 logically grouped project management processes, 10 knowledge areas, technical and management skills, methods and techniques, which facilitate a successful and sustainable project outcome (PMI 2013).

The project objectives or the critical success factors are often defined in terms of cost, schedule, and technical performance (quality). Risk assessment, on the other hand, is intended to increase the likelihood of attaining these objectives by providing a systematic approach for analysing, controlling, and documenting identified environmental impacts both during the planning and execution of a project.

The project management process itself will remain constant in different phases throughout the project life cycle. Various project management tools and techniques used for planning, evaluation, and controlling will also remain constant. What will vary, however, over the project life cycle is the quality of available risk-related information, the kind of competence that is needed to compile and filter information and the kind of decisions that are supported by the project and risk assessment activities (Sholarin 2007).

Project management is, therefore, a set of *processes*, *systems* and *techniques* for effective planning, organisation and control of resources necessary to complete a project. These processes, systems, and techniques should not only focus on the resources but should also include the control of risks and hazards associated with the exploration, development, and production of *natural resources*. Suitable project management will not only enhance the effectiveness of risk management program, but will also reduce the overall costs of the project.

3.1.2 Project Management as a Planning Tool

"First, have a definite, clear practical idea: a goal, and an objective. Second, have the necessary means to achieve your ends: wisdom, money, materials, and methods. Third, adjust all your means to that end"—Aristotle

Project management involves the process of first establishing a plan and then implementing that plan to accomplish the project objective. Once the project starts, the project management process involves monitoring progress to ensure that everything is going according to plan. The key to effective project control is measuring actual progress and comparing it to planned progress on a timely and regular basis and taking corrective action immediately, if necessary. When selecting projects and their associated work packages, planning should be done in an integrated and hierarchical manner following different levels of planning from the highest to the lowest (Kerzner 2010).

Project planning is the basis for achieving adequate attention to all the requirements of a project. The larger and more complex a project, the more critical is the need for using structured planning.

It cannot be overemphasized that planning is the initiation of progress. The difference between a ‘dream’ and a ‘goal’ is a ‘plan’. Thus, the key to a successful project is good planning. Project planning provides the basis for the initiation, implementation, and termination of a project, setting guidelines for specific project objectives, project structure, tasks, milestones, personnel, cost, equipment, performance, and problem resolutions (see e.g., Lock 2007; Turner 2009; Badiru 2008).

For a plan to be effective, it must address the following questions:

- where are we now?
- where do we wish to be?
- how do we get there?

Because projects change continually, the nature of the above elements change too. A plan, therefore, must be continually updated to reflect such changes. A plan must be dynamic and flexible to change. It should be continuously and constantly modified, detailed, and improved as newer and more improved (as well as highly detailed) sets of information become available to the project management team as the project unfolds, and takes shape. This situation is referred in project management as *progressive elaboration*.

The execution of any project involves the coordination of many activities. Projects of short duration involving relatively few resources can be planned and controlled by experienced staff without the aid of formal planning tools and techniques. However, more scientific approach is needed if the project requires the completion of numerous inter-related activities, which draw upon a common set of finite resources over extended periods of time.

Such projects would include, for example, National Contaminated Sites Demonstration Program in South Australia, Australian National Low Emissions Coal Initiative (ANLECI), Rotorua Lakes Restoration Project in Newzealand and Hydrocarbon Pollution Restoration Project in Ogoniland, Nigeria.

In projects of this kind, there are two conflicting objectives to be reconciled:

1. an aim to complete as soon as possible or by some agreed completion date.
2. the need to control cash flows and expenditure, so that liquidity problems are avoided and the project shows an acceptable return on the capital investment.

Regardless of how the above objectives are achieved, it is pertinent to note that project schedule must be realistic and include sufficient “*float*”, i.e., time contingency for delays that, from experience, can be anticipated to occur. Surveys, studies, design, and reviews must be allocated adequate time before rushing into implementation. Solid “homework” is a prerequisite for a successful project. Sufficient time must also be included for approvals (budget, technical, statutory), permits and customs clearance for imported materials.

Succinctly, project management process means planning the work and then working the plan. For example, a coaching staff may spend hours preparing unique plans for a game; the team then executes the plans to try to meet the objective, which is ‘victory’. Similarly, project management involves a process of first establishing a plan, and then implementing that plan to accomplish a given project objective. The front-end effort in managing a project must be focused on establishing a baseline plan that provides a roadmap for how the project scope will be accomplished on time and within budget. This planning effort includes the following steps (Kerzner 2004);

1. clearly define the project objective. The definition must be agreed upon by the customer and the individual or organization who will perform the project.
2. divide and subdivide the project scope into major "pieces," or when viewed as a whole, one way to conquer even the most monumental endeavor is to break it down. A work breakdown structure (WBS) is a hierarchical tree of work elements or items accomplished or produced by the project team during the project. It usually identifies the organization or individual responsible for each work package.
3. define the specific activities that need to be performed for each work package in order to accomplish the project objective.
4. graphically, portray the activities in the form of a network diagram. This diagram shows the necessary sequence, and interdependencies of activities to achieve the project objective.
5. make a time estimate of how long it will take to complete each activity. It is also necessary to determine the types and quantities of resources needed for each activity to be completed within the estimated duration.
6. make a cost estimate for each activity. The cost is based on the types and quantities of resources required for each activity.
7. calculate a project schedule and budget to determine whether the project can be completed within the required time, with the allotted funds, and with the available resources. If not, adjustments must be made to project scope, activity time estimates, or resource assignments until an achievable, realistic baseline plan (a roadmap for accomplishing the project scope on time and within budget) can be established.

Figure 3.2 illustrates project management as a planning tool, integrating scope, scheduling and budgeting processes. Planning determines what needs to be done, who will do it, how long it will take, and how much it will cost. The result of this effort is a baseline plan. Taking the time to develop a well-thought-out plan is critical to the successful accomplishment of any project. Many projects have overrun their budgets, missed their completion dates, or only partially met their requirements because there was no viable baseline plan before the project was started.

Careful planning is therefore required to ensure that a project is completed on time and within budget. In part III, techniques to assist in the planning of environmental projects are discussed. These include project management techniques such as delphi techniques, scope planning techniques, cost estimating techniques, schedule compression techniques, program evaluation and review techniques (PERT), as well as environmental management techniques such as checklists, systems diagram, networks. These techniques are applied using geospatial tools, such as geographical information systems (GIS), photogrammetry, and global navigation satellite systems (GNSS) (see, e.g., Awange and Kiema 2013). Application of these techniques to assist in scheduling activities so that project finishes within the minimum feasible

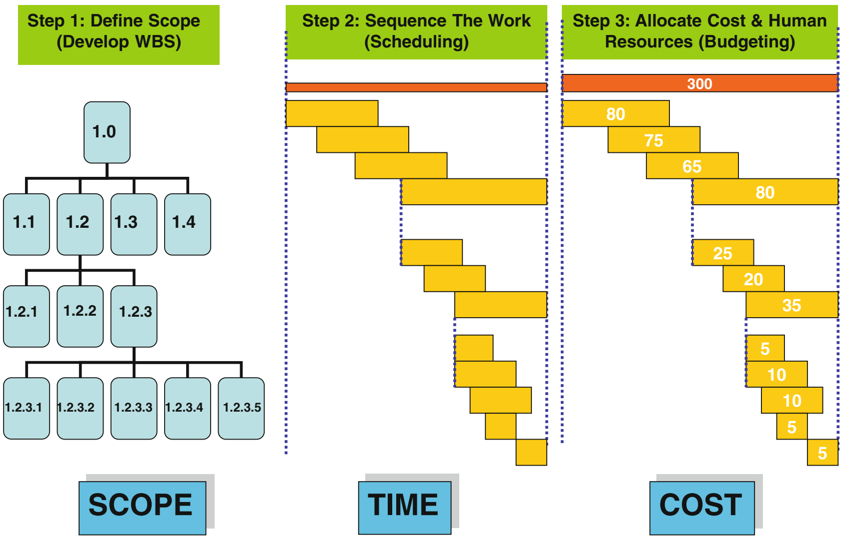

Fig. 3.2 PM as a planning tool showing scope, schedule and budget integration

time is demonstrated. The possible rescheduling of activities taking into account limitations on certain critical resources is also considered.

Project planning is the process of scheduling activities and allocating resources at the start of the project in such a way that it is possible to complete in the required time and at the required cost. It deals with the interrelationships between, and the timing of the various activities that comprise a project. Detailed planning of a project entails identification of the activities that comprise a project, estimation of the duration of each activity, identification of the precedence relations between activities (i.e., which ones need to precede others) and development of an organizational network or schedule that represents this information accurately. Such organizational network can be used to provide the following information (Wideman 1991);

- the minimum time to complete the project, if all activities run on time;
- the activities that are critical to ensure that a project is completed in the shortest time possible;
- the earliest start time and the latest finish time for each activity, if the project is to be completed in the shortest time possible; and
- the amount of time by which each activity can be delayed without delaying the project as a whole.

An organizational network can also be used to examine the likely timing of resources (human resources, cash, and equipment) required over the duration of the project and whether limits on these resources are likely to cause delays in the project completion. Furthermore, an organizational network can be used to identify which activities should be accelerated if the project needs to be completed in a shorter time than the current estimate with the aid of a schedule compression technique.

One of the primary benefits of quality planning is the ability to accurately monitor and evaluate progress during project execution. A project management tool called *earned value analysis* (EVA) is used for such evaluation (Fleming and Koppelman 2000). The tool is used to identify schedule and cost variances, which may occur during project execution. Such variances are usually documented in status reports to operations' management and the customer, forming basis for management decision making process.

3.1.3 Project Management as a Decision-Making Tool

> *"Unless commitment is made, there are only promises and hopes; but no plans"—Peter F. Drucker*

Decision science (see, e.g., Kahneman and Tversky 1979; Clemen 1991), as a project management tool, helps environmental managers and other decision makers to evaluate and select alternatives, process huge amount of information, make a correct and intelligent decision, assess and interpret probabilities of potential events or risks. Managers often use decision analysis as an aid to identify specific mental patterns and come up with an informed decision.

Decision analysis is used to select the best course of action in situations where a decision-maker faces uncertainty. Decision analysis (often referred to as decision tree analysis, e.g., Schuler and Newendorp 2000) is a specific technique, in which a diagram is used for the purpose of assisting a project manager, as well as, the project team in making a difficult decision. The decision tree is a diagram that presents the decision under consideration and, along different branches, the implications that may arise from choosing one path or another. The decision tree analysis is often conducted when a number of future outcomes of scenarios remain uncertain. The decision tree analysis takes into account a number of factors including probabilities, costs, and rewards of each event, and decision to be made in the future. Decision analysis uses expected monetary value analysis to assist in determining the relative value of each alternate action. A framework for decision-making analysis is illustrated in Fig. 3.3. Project management as a decision-making tool for analyzing project situations under uncertainty is illustrated in Sect. 7.3.3 and Fig. 7.5.

Many companies in the petroleum sector often base their major investment strategies on the results of decision analysis. Such companies will never proceed with any major projects without comprehensive formal decision analysis. For example, a petroleum engineer must decide which oil prospects to develop first taking into account potential uncertainties in estimation of oil reserves. A drilling engineer must decide whether to drill or not to drill. A petroleum asset manager must decide whether to buy a green field or a brown field before knowing if it can produce hydrocarbon in commercial quantity.

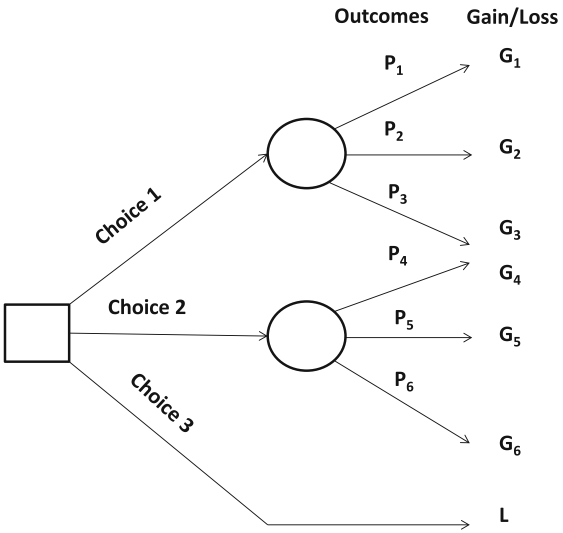

Fig. 3.3 A framework for decision-making analysis, showing graphical device for analyzing project situations under risk: P_s are the outcomes of probabilistic events for respective choice taken, while G_s and L_s are the payoffs (gains or losses)

In all these cases, the decision maker faces uncertainty that seems to make it impossible to choose the right option with any certainty. Although a decision-maker does not know what the outcome of the unknown will be, he or she generally has some knowledge about what the possible outcomes are and how likely each is to occur. This information can then be used to select the option that is most likely to yield favorable results.

An application of project management as a decision-making tool is discussed in Chap. 7: Environmental risk and decision analysis.

3.1.4 Project Management as a Resource Optimization Tool

"Time is the scarcest resource and unless it is managed nothing else can be managed."—Peter F. Drucker

In project management, resource management or resource allocation is the scheduling of activities and the resources required by those activities while taking into consideration both the resource availability and the project time. Resource management is used to assign the available resources in an economic way.

Resource loading for project management is different from that experienced in typical upstream production operations management. Project management typically exhibits temporary organisations driven by frequent review of project progress and direction. Expertise and capability move in and out of the project as and when needed. Project managers view entire project with an emphasis on the final outcome and use resource levelling heuristic techniques to examine unbalanced use of project resources (usually people, equipment, or materials) over time, and for resolving over-allocations and clash in use of resources between the human resource (HR) manager and project manager.

When performing project planning activities, a project manager will attempt to schedule certain tasks simultaneously. When more resources are needed than are available, or perhaps a specific person is needed in both tasks, the tasks will have to be rescheduled concurrently or even sequentially to manage the constraint. Resource levelling heuristics, is the technique used to resolve such conflicts. It can also be used to balance the workload of primary resources over the course of the project, usually at the expense of one of the traditional "Time-Cost-Quality" constraints.

Figure 3.4 illustrates project management as a resource optimization tool, showing how the resource available at a given day(12 operators) is matched with the number of resource required. The idea is to ensure that the resource required at any time never exceed the total number of resource available.

In concluding, it must be emphasized that the success of project management depends not only on the tools and techniques applied. If an organisation is set up as a line (functional) organisational structure and project managers struggle to have control over their resources, the best tools and techniques will be of limited value. Organisational boundary conditions must be set for the success of project management as an indispensable tool for achieving outstanding business results.

WBS ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
START	0	0	0													
B	4	4	4													
C	5	5														
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END														2	2	2
TOTAL	**9**	**9**	**9**	**12**	**12**	**12**	**7**	**7**	**7**	**7**	**12**	**12**	**12**	**2**	**2**	**2**
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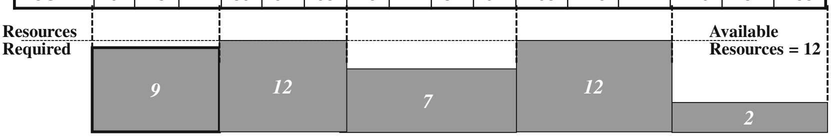


Fig. 3.4 Project management as a resource optimization tool

3.1.5 The Triple Constraints of Project Management

Every project is constrained in different ways by its time, cost and performance goals. These limitations, in project management, are called the "*project management triangle*" or the *triple constraints* (see, e.g., Lock 2007). Projects are typically performed under limited budgets, time pressure, tight cash flows, and uncertainty using shared human, material, and financial resources. The triple constraints of time, cost and quality requires the project manager and his/her team to constantly make trade-offs between these factors with the implicit goal of balancing risks and benefits.

Project management can be viewed as a three-legged stool or "iron" triangle with three main components as its axes:

- Time/Schedule
- Cost/Budget
- Quality/Performance/Specification.

When one leg is shorter than the others or non-existent, the triangle cannot be used for its designed purpose. Figure 3.5 is often used to illustrate the three dimensions of the triple constraints by determining project team's ability to control the project so that the expected results are produced while managing time, cost and quality requirements. Each area–time, cost, and quality—forms the baseline at the beginning of the project.

The triple constraints in Fig. 3.5 is depicted as a triangle with cost, time and quality requirements at the sides of the triangle. Based on the project management institute's definition of project management, it could be said that the whole three constraints contain customer expectation and project objectives that could be considered figuratively to be the interior of the triangle, since the customer should always be concerned about time, cost as well as quality of the deliverables.

Project managers need to constantly balance customer or internal client expectations against achievement of socio-economic and environmental goals, as reflected in the project objectives. Project scope, objectives, roles and responsibilities, quality

Fig. 3.5 Three dimensions of the triple constraints

standards, deliverables, cost, and schedule should all be clearly delineated and agreed upon from the outset. Risks must be identified, quantified, assessed, and responded to properly to ensure customer expectations and project objectives are balanced. The impact of risk events can tip the scale in either direction.

Any project can be done successfully, if there is no constraint on time or there is unlimited budget available. But unfortunately that is not true in real life. A project is performed within some constraint and usually these constraints are competing. So, if one is changed, it would impact the other. For example, if the customer wants to shorten the schedule, there is likely to be an increase in cost or a reduction in the deliverables or both. if additional work is added to the project scope, by customer's request—a situation called "*scope creep*" (see, for example, Vaidyanathan 2013); or by project team in order to exceed customer's expectation,—a situation called "*gold platting*" (see, PMI 2013), there is likely to be an increase in cost or schedule or both. If the customer or project sponsor wants to reduce the cost of the project and shorten the schedule, quality of the deliverables will probably has to be reduced. Thus in order to satisfy customer expectation, project must be delivered according to what was promised, within the available budget that was promised and when it was promised.

The relationship between the three constraints (time, cost, and quality) is given by the following expression (see e.g., Badiru 2012);

$$S = f(T, C, Q) \tag{3.1}$$

where the stakeholder (or customer) satisfaction (S) is a function of time (T), cost (C), and quality (Q). The cost is usually measured in dollars, pounds, francs or whatever currency of the realm but may sometimes be measured in the number of labour hours. The triple constraints of time, cost and quality are known in the PMBoK guide as the planning and controlling functions of project management (see, PMI 2013).

The interrelationship among the triple constraints varies. For example, sometimes it is necessary to compromise the quality and scope of the project to get the project done quickly or less expensively. Often, the longer a project takes, the more expensive it becomes. However, a positive correlation between cost and schedule may not always be true (see, e.g., Hulett 2012).

Sometimes, project costs can be reduced by using cheaper, less efficient labour or equipment that extends the duration of the project. Likewise, as will be seen later in the book, project managers may be forced to expedite or "crash" certain key activities by adding additional labour, thereby raising the original cost of the project (e.g., Harrison and Lock 2004).

Figure 3.6 illustrates the practical relationship between the triple constraint parameters. At a given level of performance (quality), a particular schedule will result for a particular budget. If more budget is available (which will be represented by a lower curve than is drawn in the figure), more effective resources may be applied to the project to improve performance, and the schedule can be shortened.

Figure 3.7 illustrates various triple constraint outcomes and their relationships. For example, quality that is better than required is normally obtained only if there

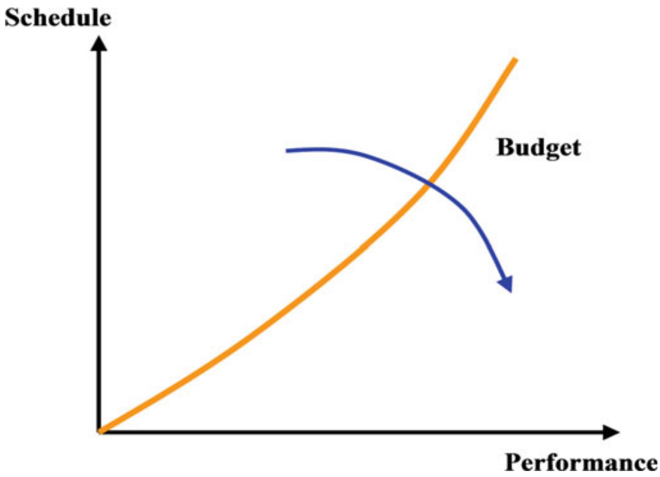
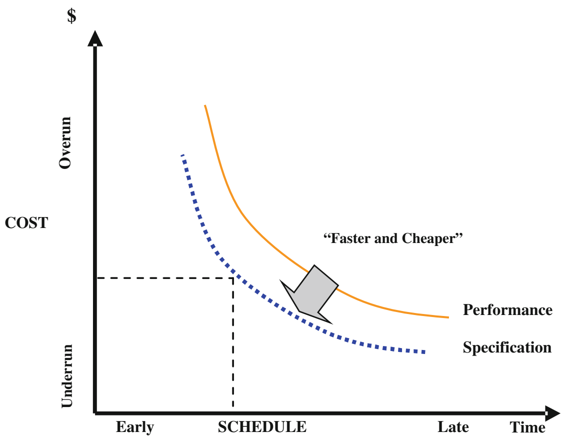


Fig. 3.6 The triple constraints trade-off

Fig. 3.7 The triple constraints outcomes, illustrating the trade-offs between cost, time and quality (For example, project costs can only be reduced at the expense of schedule delay or poor performance.)



is a budget overrun or a late delivery, and most frequently when both occur. This illustrates why it is so important for the project manager to moderate the enthusiasm of technical experts, who can always see the possibility of doing better and are eager to achieve better quality (an example of *gold plating*).

In preparing project plans, therefore, it is worth understanding the key drivers for the project. Which is important: quality, cost, or schedule? Projects are successful if they are completed on time, within budget, and to performance standards. Oftentimes, customer or project sponsor want to increase the scope, reduce the time and cost, and the burden of meeting these three constraints is on the project manager. It is the responsibility of a competent project manager to balance the trade-offs between the scope, schedule, and budget.

3.1.6 The Project Life Cycle

Project is a "temporary endeavor undertaken to produce a unique product, result, or service" (PMI 2013). It is a transitory and temporary effort designed to achieve a unique goal with a specific set of objectives, which means it has its own life cycle. Consequently, it is important to identify the phases that accompany the transformation of an idea or a concept into a product or a system. The collection of such phases is defined as the *project life cycle* (Harrison and Lock 2004).

A conventional project life cycle is characterised by an S-curve (cumulative cost over time) pattern whose bottom tail at time zero, and the top tail corresponding to the project completion (Wideman 1991). This is illustrated in Fig. 3.8.

In the early stages of a project, the level of resource commitment and utilization is typically low as efforts focus mainly on developing the project concept and assessing its feasibility. All projects have phases and a life cycles. In fact, the cumulative S-curve derived from a project life cycle forms the basis of project scheduling and performing the earned value analysis, discussed in Sect. 15.5: Project performance evaluation tools.

Every engineering project, over the course of its life cycle, can be grouped into the following distinct phases, through which it passes over a period of time;

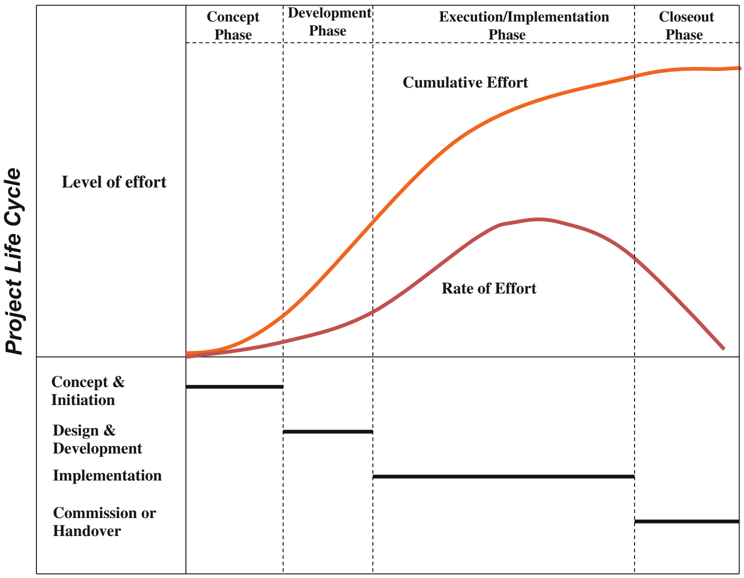


Fig. 3.8 A typical project life cycle showing the phases that accompany the transformation of an idea into a finished product or system

1. initiation or conceptual phase;
2. planning and engineering Design phase;
3. execution or implementation phase; and
4. close-out or finalisation phase.

Although project phases are applicable to any sort of project, a discussion of the activities that typically occur in each phase is appropriate.

3.1.6.1 Initiation or Conceptual Phase

Project initiation phase is when a need is identified and background data are collected. Goals, objectives, project constraints, risks/opportunities, and feasibility studies are developed during this phase. For example, for oil and gas projects, seismic surveys are carried out during this phase following a licence award to develop a picture of geological structures below the surface, using survey techniques such as gravity, magnetic, and electro-magnetic. If results show structures exist that are potential hydrocarbon reservoirs (prospects), an oil and gas company (operator) may then proceed with site surveys (see, e.g., Badiru and Osisanya 2013).

Site surveys are carried out to gain more information about the area of a potential prospect, including data on the environment around a potential drilling location. If the results support the identification of a prospect, and a safe and environmentally viable drilling location is identified, the operator may then proceed to the planning and engineering design phase.

3.1.6.2 Planning or Engineering Detailed Design Phase

During this phase more detailed planning occurs. The initial project definition is reviewed, and refined, and detailed designs are developed. During the development phase, project team usually expands to include people from various disciplines (e.g., petroleum engineers, drilling engineers, geologists, reservoir engineers, planning engineers, petroleum economists, risk analysts, etc.). It is at this phase that project management documents such as, responsibility assignment matrix (RAM), work breakdown structure (WBS), network diagram, Gantt chart, resource histogram, and risk assessment matrix are developed.

In the case of oil and gas project for example, one or more exploration wells are drilled at this phase to determine if a prospect exists and to gain further data on the subsurface conditions. If a hydrocarbon reservoir is encountered, the well is surveyed using specialist well-logging tools, and tested to see whether the reservoir is viable for production, in which case the operator may proceed to appraisal drilling. Well testing provides hydrocarbon samples and information on flow rate, temperatures, and pressures. If no viable reservoir is encountered, an operator may carry out further drilling if the initial results indicate that hydrocarbons may still exist elsewhere in the licenced area. Unsuitable wells for further development are sealed and tested to ensure they are fully secure before being abandoned.

If, on the other hand, promising amounts of oil and gas are confirmed, then field appraisal is used to establish the size of the field and the most appropriate production methodology to assess whether the field is commercial. Appraisal may take several years to complete. Appraisal wells are drilled to confirm the size and structure of the field and well logging (analysis) provide data on the hydrocarbon-bearing rocks. If appraisal confirms a commercial reservoir, the project may then proceed to implementation and execution phase (see e.g., Badiru and Osisanya 2013).

3.1.6.3 Execution or Implementation Phase

During the execution phase, the detailed design plans are implemented. The planned work packages from the WBS are converted into actual deliverables, and the quality, cost, and time objectives of the projects are targeted for achievement. This phase is called the development phase in the oil and gas industry (Badiru and Osisanya 2013).

At this phase, once a prospect has been shown to be technically and commercially viable, a development plan is submitted to the department of petroleum resources for approval. Before the field is developed, materials and services are procured and equipment is manufactured and installed, including the system for transporting oil or gas to the sales point. Production wells are drilled using horizontal, vertical, or multilaterial drilling. Once development drilling is complete, the facility is commissioned to achieve a stable production level. Finally, the development facility comes on-stream and starts production.

In the petroleum exploration and production operations, a large number of options exist for field production, depending on the type (oil or gas), the location, and the environmental conditions. Once the development is online, production is gradually increased to peak production. This is maintained for a time before it starts to decline, at which time it may be feasible to inject water or gas into the reservoir to maintain production levels, or drill new wells in nearby reservoirs and connect these to the facility (see, e.g., Marler 1994).

3.1.6.4 Close-Out or Finalisation Phase

The close-out phase is the point where the project outcome is integrated and the results of the project are documented, resources released, and responsibility for the newly developed product is transferred. When an oil and gas company decides that the production facility is no longer economically viable, the company shuts the facility down, make it safe, and leaves the environment in an acceptable condition.

Unlike petroleum, mining and other engineering projects, an environmental project will often be determined by the regulatory program, which is driving the project. For example, if a project falls under the domain of the *Contaminated Sites Act* 2003 (CS Act), the industry specific phases would correspond to preliminary site investigation (PSI), detailed site investigation (DSI), remediation, risk assessment, feasibility study, validation and monitoring. The phases can be broken up into a number of project-specific tasks, for the purpose of scheduling, budgeting, monitoring and controlling the work. A detailed discussion of tasks specific to an environmental project management is provided in Sect. 3.4.2.

3.1.7 Project Organisation Structure

Prudent companies realise that organisational structure must be dynamic in nature; that is, they must be capable of rapid restructuring should environmental, social and economic conditions dictate. These sustainability factors evolved from the increasing competitiveness of the market, changes in technology, and a requirement for better control of resources for multi-product companies (see, e.g., Kerzner 2010).

The rapid rate of change in both modern technology and the marketplace has created enormous strains upon existing organizational structures. The *traditional organisational structure*, a structure, where the general manager has beneath him/her all of the functional entities necessary to either perform a service, develop or manufacture a product, is highly bureaucratic and experience has shown that it cannot respond rapidly enough to a changing environment. Thus, the traditional structure must be replaced by a strong project-based organisational structure, which are highly organic and can respond very rapidly as situations develop inside and outside the company (see, e.g., Kerzner 1982, 2004 and 2010).

There is no universal system of organisation that suits all circumstances. Project organisation structure are temporary in nature, but often have to interact with external (contractor's organisation structure) and internal organisation structures. The manner in which these interactions take place will have an influence on what the project organisation structure can achieve. The type of project organisation structure suitable for a company depends on three main issues:

1. team mix requirements;
2. contracting strategy, e.g., engineering, procurement and construction management(EPCM) contract or engineering, procurement and construction (EPC) contract.
3. project challenge (e.g., standard project, new venture or frontier project, complex or innovative project).

Every organisation, large or small, is influenced by the hierarchy of the organisation and how the roles of the members of the organisation are defined. A rigid system of role definition and responsibility creates a sense of stability in that there is a place for everyone and everyone knows their place, creating room for bureaucracy. However, this approach may stifle flexibility, creativity, and prompt decision making. More recent approaches to role definition was proposed by Meredith Belbin, in his book, "Team roles at work" (Belbin 1993). By this approach, roles are defined to allow for more autonomy and scope for individual innovation.

There are three major ways to organize and accomplish project activities. Nearly every organization fits one of these types, or a combination of them. These are:

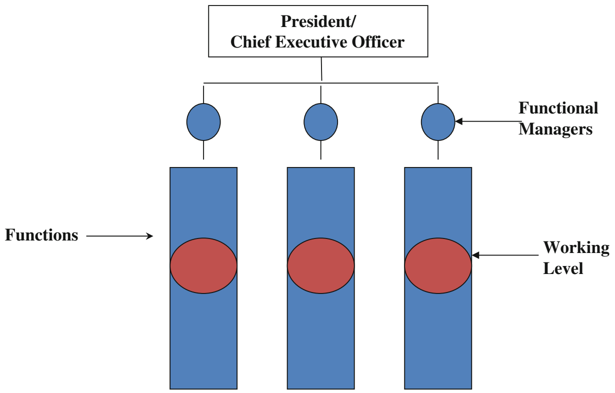
1. functional or multi-disciplinary organisation structure,
2. matrix organisation structure and
3. pure project management organisation structure.

The functional and pure project organization structures have been around for hundreds, probably thousands of years. However, the matrix structure is a rather recent development (see, e.g., Allianz 2004). Many organisations use the functional, matrix or pure project organisational structures, which show hierarchical relationships between individuals or teams of individuals. These structures are discussed in detail below with examples provided.

3.1.7.1 Functional Organisation Structure

The most common type of formal organisational structure is known as the functional or traditional organisation structure, whereby people are organised into groups (divisions) dedicated to particular functions. Depending on the size and the type of auxiliary activities involved, several minor, but supporting, functional units can be developed for a project. Projects that are organised along functional lines normally reside in a specific department or area of specialisation. The project home office or headquarters is located in the specific functional department.

The functional organisation structure, as shown in Fig. 3.9, was found by Kerzner (2010) to be satisfactory where control and conflicts were at a minimum. However, as times progressed, companies found that survival depended upon multiple product lines (i.e., diversification) and vigorous integration of technology into the existing



People work within their functional organization with little cross-functional coordination

Fig. 3.9 Functional organisation structure organisation. As organisations grew and matured, managers found that company activities were not being integrated effectively, and that new conflicts were arising in the well-established formal and informal channels.

As seen in Fig. 3.9, the functional manager has beneath him all of the functional entities necessary to perform project activities. All activities are performed within the functional groups and are headed by a department (or, in some cases, a division) head. Each department maintains a strong concentration of technical expertise. Since all of the project must flow through the functional departments, each project can benefit from the most advanced technology, thus making this organisational form well suited for mass production. Functional managers can hire a wide variety of specialists and provide them with easily definable paths for career progression.

The functional managers maintain absolute control over the budget. They establish their own budgets, upon approval from above, and specify requirements for additional personnel. Because functional manager has manpower flexibility and a broad base from which to work, most projects are normally completed within cost. Both the formal and informal organisations are well established, and levels of authority and responsibility are clearly defined. Since each person reports to only one individual, communication channels are well structured. If an organisational structure has these many advantages, then why are we looking for a better management structure?

According to Grinnell and Apple (1975), there are five general indications that the functional structure may not be adequate for managing projects;

1. management is satisfied with its technical skills, but projects are not meeting time, cost and other project requirements;
2. there is a high commitment to getting project work done, but great fluctuations in how well performance specifications are met;
3. highly talented specialists involved in the project feel exploited and misused;
4. particular technical groups or individuals constantly blame each other for failure to meet specifications or delivery dates; and
5. projects are on time, on target and to specifications, but team members aren't satisfied with the achievement.

Consequently, managers began searching for more innovative organisation structure that would alleviate the integration and conflict problems.

3.1.7.2 Project-Based (Projectized) Organization Structure

Project-based, sometimes called *pure organisation structure* or *projectized organisation structure* in PMBoK, on the other hand, develops as a division within a division (see Fig. 3.10). As long as there exists a continuous flow of projects, work becomes stable, and conflicts are at a minimum. The major advantage of this structure is that one individual, the project manager, maintains complete line of authority over the entire project. Not only does he assign work, but he also conducts merit reviews for budget, schedules, and deliverables. Because each individual reports to

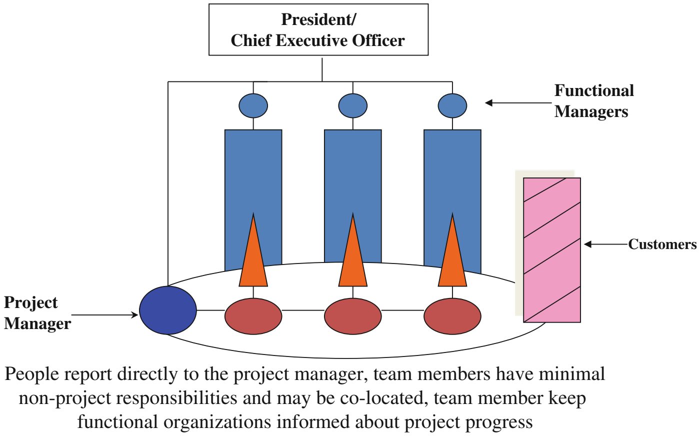


Fig. 3.10 Project-based or pure organisation structure

the project manager, team members have minimal non-project responsibilities and may be co-located. Project team has direct contact with the clients or customers. However, team members are required to keep their functional managers informed about project's progress. As a result of this, functional managers were able to maintain qualified staffs for new development without sharing personnel with other programs and projects.

The real problem with the project-based organization structure is what to do with the project team when the project is completed. One can picture a project team in Nigeria's Niger Delta Hydrocarbon Pollution Restoration project (HYPREP). The goal of the project was to perform a cleanup operation within a period of 5 years with an estimated cost of \$1 billion. The goal was achieved; project was completed on time, on budget, and all stakeholders were satisfied. Everyone celebrated while project team members were handed termination notices.

Thus, it may seem that the project-based organisation structure should be the best type of organisation structure for managing very complex projects. In reality, it is not good for a project-oriented organisation in which projects are the major part of its long-term activities. Project-based organisation structure is only useful for companies that employ outsourcing services, where project team members work directly for, and only report to the project manager of the client companies. These team members are employed as contractors on fixed-time basis.

3.1.7.3 Matrix Organisation Structure

Projects work best in balanced matrix type of organization. This is because the resources of the company are permanent and projects are "one-off" and temporary endeavor. Project teams are formed for the entire project life cycle. This means that right resources are brought together at the appropriate project phase and used for the amount of time they are needed. But where do they come from and where do they go when the project's mission is accomplished?

While trying try to answer this question, another question comes to mind. What is the most efficient type of organisation for managing projects? To be able to answer this latter question, it is pertinent to take a look at the two types of matrix organizational structure developed and used across various industries and compare their pros and cons.

Weak Matrix Organisation Structure

The matrix organisation structure is an attempt to combine the advantages of the functional and the project-based organisation structures. Figure 3.11 shows a typical weak matrix structure. The combination facilitates maximum resource utilization and increased performance within the triple (cost, time and, quality) constraints.

Under weak matrix structure, project team work within their functional organizations with the project manager serving as a cross-functional coordinator. Each project manager reports directly to the general or functional manager, who then reports to the CEO or the president of the company. The project team has no direct contact with the clients or customers.

For example, all engineers may be in one engineering department and report to an engineering manager, but these same engineers may be assigned to different projects and report to a different engineering manager or a project coordinator, while working on that project. Therefore, each engineer may have to work under several managers to get his or her job done.

Strong Matrix Organisation Structure

A strong matrix structure (Fig. 3.12) is frequently used in the resource exploration and production industry because they are mostly project-driven. Under this structure, there are usually two chains of command involving both horizontal and vertical reporting channels. The horizontal line deals with the functional reporting channel of responsibility, while the vertical line deals with the project reporting channel of responsibility. The strong matrix structure provides the best of two worlds: the

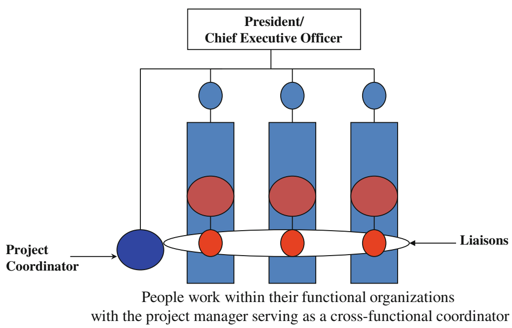


Fig. 3.11 Weak matrix organisation structure

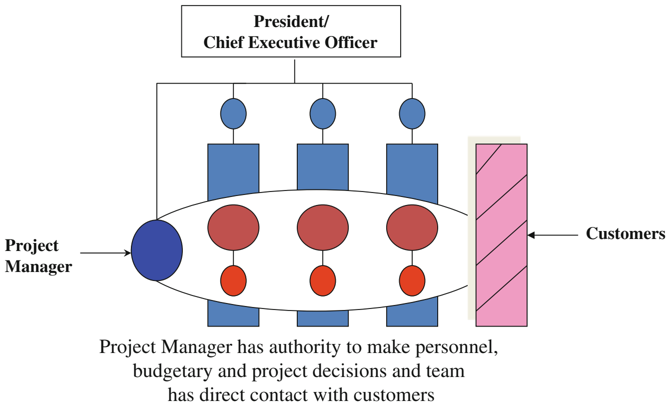


Fig. 3.12 Strong matrix organisation structure

functional and the project-based organisation structures. Here, the project manager has the authority to independently establish his own project policies and procedures, provided that they do not conflict with company policies. This can do away with much red tape and permits a better balance between time, cost and quality (performance) (Kerzner 2008). The Project manager also has authority to make personnel, budgetary, and project decisions, and the team has direct contact with customers. Consequently, the project team is able to provide rapid response to changes, conflicts, and other project needs whenever they arise.

The advantages of strong matrix structure include the following (see, e.g., Kerzner 1982; Badiru 2008);

1. resource optimization and manpower utilization,
2. better balance among the triple project management constraints of time, cost and quality,
3. policies and procedures can be set up independently for each project, provided it does not cause conflicts with other projects,
4. improved productivity of skilled personnel,
5. establishment of Project Management Office (PMO), which can be used effectively as a refuge for project team members,
6. conflicts are minimal, and those requiring hierarchical referral are more easily resolved, and
7. rapid response to change, conflict resolution and project needs.

On the other hand, the disadvantages of a strong matrix structure include (see, e.g., Kerzner 1982; Badiru 2008);

1. each project organization operates independently,
2. more time and effort is needed initially to define policies and procedures,
3. balance of power between functional managers and project managers,
4. optimization of time, cost and quality (project performance),

5. additional cost due to new line of command, and
6. response to problem resolution may be too slow, especially on fast-moving projects.

Strictly speaking, matrix organisation structure is the practice of managing individuals with more than one reporting line, but it is also commonly used to describe managing cross functional, cross business group, and other forms of working that cross the traditional vertical business units, for example, department, silos, etc. Organisation structure in itself is not the end, but the means, of achieving organisation and project goals. People have to interact within these structures to achieve success.

The summary for the pros and cons of various organisation structures is shown in Table 3.1.

3.1.8 Leadership in Project Management

"Management is doing things right; leadership is doing the right things."—Peter F. Drucker

You are probably not alone in wondering why organisations aren't working effectively and efficiently. Many of us are troubled by questions that haunt our work. Why do so many organisations feel lifeless? Why do projects take so long, cost so much, develop ever greater complexity, yet too often fail to achieve any truly significant results? Why does progress, when it appears, so often come from unexpected places, or as a result of surprises or synchronistic events that our planning had not considered? Why does change itself, that event we're all supposed to be "managing," keep drowning us, relentlessly making us feel less capable and more confused? And why have our expectations for success diminished to the point that often the best we hope for is endurance and patience to survive the frequent disruptive forces in our organisations and lives? These were the similar questions asked by Wheatley (1999) in her book: "Leadership and the new science". There is a simpler way to lead organisations, one that requires less effort and produces less stress than our current practices.

Leadership, as described by Pochron (2009), is an on-going process that occurs as a result of formal and informal interactions within the organization. This dynamic process is initiated whenever a leader recognizes the need for a change, perceives the possibilities for the change, and consequently takes action. Because of the diverse approach to describing leadership, researchers have not reached a consensus as to what it really means (Butler and Chinowsky 2006).

The ability to make a correct decision at the right time makes a leader a good one indeed and others can emulate such as a result of behavioral influence, because leadership is about exerting influence in a way that invigorates others to comply willingly with a desired goal (Wheatley 1999; Pochron 2009; Burke and Barron 2014). This, of course, calls for a significant mastery over the leaders' behavior and

Table 3.1 Pros and cons of different organisation structures

Type of organisational structure	Strengths	Weaknesses
Functional structure	1. Easier budgeting and cost control	1. No individual is directly responsible for the total outcome of the project
	2. Better schedule and quality control	2. Conflict between project objectives and regular functions
	3. Provides flexibility in the use of manpower	3. No provision for project-oriented planning necessary to accomplish the project tasks
	4. Provides continuity in the functional disciplines, policies and procedures	4. Decisions normally favour the strongest functional groups
	5. Provides good control over personnel	5. Customer is not the focal point, but rather the higher-level management
	6. Communication channels are vertical and well established	6. Lack of motivation, creativity and innovation
Matrix structure	1. Project manager maintains maximum control over cost, time and resources	1. More efforts and time is needed initially to define policies and procedures
	2. Rapid responses are possible to changes, conflict resolution and project needs	2. Balance of power between functional and pure project structure may become an issue
	3. The functional organisation structure exists primarily as support for the project	3. Functional managers may be biased according to their own set of priorities
	4. Conflicts are minimal, and those requiring hierarchical referral are more easily resolved	4. Their may be duplication of efforts between project managers and functional managers
	5. Better balance between time, cost and performance	5. Response to problem resolution may be too slow, especially on fast-moving projects
	6. Improved productivity of skilled personnel	6. Additional cost due to new line of command
Pure project organisation Structure	1. Provides complete line of authority over the project, i.e., strong control through a single project authority	1. Lack of career continuity and opportunities for project personnel
	2. Project team members work directly for the project manager	2. Cost of maintaining this type of structure can be prohibitive due to inefficient use of facilities and personnel
	3. Strong communication channels	3. Lack of opportunities for technical interchange between projects
	4. Flexibility in determining time, cost and performance trade-offs	4. There exists a tendency to retain personnel on a project long after they are needed
	5. Better interface management among different functional areas	

attitudes in a sacrificial manner to be able to exercise the greatest influence on other employees.

Dr. Harold Kerner, arguably a modern project management guru, defined leadership as a style of behavior designed to integrate both the organizational requirements and one's personal interests into the pursuit of some objective (Kerzner 1982). The PMBoK Guide, 5th edition, defines leadership as "developing a vision and strategy, and motivating people to achieve that vision and strategy" (PMI 2013). All project managers must have some sort of leadership responsibility.

It is common practice today that a project manager is assigned with the authority and responsibility to manage a project in a constraining and ferociously competitive environment. The project manager should therefore be able to undertake the functions of organising, planning, staffing, directing, and controlling the project to enable the management of the budget, work plan, and all project management procedures including scope management, issues management, risk management, and so on, to achieve the objectives of the project within the requisite time frame and budget.

A project manager is often regarded as a project leader, playing a significant role in not merely managing but also leading the project team to achieve the objectives of the project (see, e.g., Muller and Turner 2012; Burke and Barron 2014; Northouse 2007). Nonetheless, not all project managers are project leaders.

Indeed, leadership is essentially not about motivating people and directing the behavior of others towards the accomplishment of a common goal. It is about influencing other people to get things done to a standard and quality above their norm, and doing it willingly (Northouse 2007). Good companies don't hire skilled people and motivate them; they hire already motivated people and inspire them. People are either motivated or they are not. Unless motivated people are given something to believe in, something bigger than their job to work toward, they will motivate themselves to finding a new job (Sinek 2009a, b).

Frequently, leadership is interpreted as the purview of those "in charge": presidents, business-unit managers, and decision executives. Yet this top-down, command-and-control type of leadership may, in fact, be part of the problem in that everyone is expecting someone else to lead. Rather, everyone involved in the project management process has a leadership role. Leaders are people "who inspire with clear vision of how things can be done better" (Slater 2001).

Successful leaders do the following (see e.g., Badiru 2008; Muller and Turner 2012; Kerzner 2010);

- understand their personal strengths and weaknesses and their companies values and worldviews,
- often humble and generous in their knowledge sharing,
- confidently innovate and adapt to embrace an uncertain and dynamic world,
- always give credit where due and is open to fresh ideas from his/her team members,
- engage others with a positive and caring attitude, and
- energise themselves and others through heroic ambitions.

The most inspiring leaders ask "why" an organisation does what it does. This simple question has power to encourage other team members to achieve extraordinary things (Sinek 2009a, b).

Good leadership lessons can be learned from a Chinese proverb that says,

- Tell me, and I forget;
- Show me, and I remember;
- Involve me, and I understand.

Telling, showing, and involving are good practice of leadership in modern project management.

3.2 Project Management Standards and Processes

Standards form an important building block of any profession (Crawford 2007). They capture the body of knowledge that provide guidance for individuals and organizations practicing the profession and for the development of professionals. For all projects and project management, several standards can be identified. Some relate to the process of performing or managing projects, some to the competencies or qualifications of the project manager and some to the organization that commissions projects. Most commonly used and internationally recognised standards include ISO14001:2004 Environmental management system, the NORSOK Risk and Emergency Preparedness Analysis Standards (NORSOK 2002), which were developed by the Norwegian petroleum industry to ensure adequate safety, value adding, environmental and cost effectiveness for petroleum industry developments and operations in Norway; ISO9001:2008 Quality management system, based on PDCA circle and Six Sigma methodology, a set of tools and techniques used for process improvement, and recently released International Organisation for Standards, ISO21500:2012 Guidance on project management. The latter provides high-level description of concepts and processes that are considered to form good practice in project management.

Table 3.2 presents an overview of four different standards and their processes. It is very clear from the table that there are direct connections between ISO21500:2012 Guidance on project management and the rest of the standards.

Especially in the processes the first three standards are almost identical. The differences between the standards appear to be more notable, but the continuous improvement process, an iterative cycle of "Plan-Do-Check-Act", is shared by all the four standards.

For the purpose of this book, we selected the project management institute's body of knowledge (PMBoK) Guide, which is acknowledged by the American National Standards Institute (ANSI) as the most recognised and the most influential standard on project management, because of the distribution of the Guide and the popularity of the related project management professional (PMP) certification process. The PMBoK Guide defines project management "best practices" in terms of processes,

Table 3.2 Comparison of various standards and their processes

ISO21500:2012 PMBoK guide®	ISO 9001:2008 Quality management system	ISO 14001:2004 Environmental management system	ISO 31000:2009 Environmental risk management
Initiate	Define	Define	Identify
Plan	Measure	Plan	Qualify
Execute	Analyse	Implement	Quantify
Control	Improve	Review	Assess
Closeout	Closeout	Continual improvement	Closeout

tools and techniques, inputs, outputs and formats. Although, PMBOK Guide may be considered as a good foundation for a good project management methodology, unless adapted to fit in with the existing processes of the organisation under review, it cannot be considered as a methodology.

In the project management body of knowledge (PMBoK Guide), project management processes are presented as discrete elements with well-defined interfaces. Project management is achieved using established processes. A process is defined as a "set of interrelated actions and activities that are performed to achieve a pre-specified set of products, services or results, with defined inputs and outputs" (PMI 2013; Vaidyanathan 2013).

Managing projects is riskier than everyday management. The characteristics that make project management unique is that something must be done, which has not been done before. There are more specific expectations to be accomplished in a specific timeframe, and with limited resources.

Because project management is riskier than everyday work, a project manager should follow five distinct steps (initiation, planning, execution, controlling and closeout) in order to be successful:

- **Initiation**: Defining top level goal and specific objectives in concrete terms. List all the specific objectives and prioritize them with the most important first.
- **Planning**: Develop *Scope Statement* with clearly stated goal and objectives. State the specifications for the project. List all activities for the objectives and organize the project, using the work breakdown structure (WBS).
- **Execution**: Establish a starting time for integrating and committing resources (assets, facitilites, equipments, and human resources, (including subcontractors) that will result in executing the project activities effectively and efficiently.
- **Controlling**: Obtain feedback at each stage of project implementation on how the project is comparing to initial projections. Inspect continuously. Controlling - measuring performance, taking corrective action, ensuring compliance, reassessing control plans, responding to risk event triggers.
- **Closeout**: Organise acceptance of the product, service or result, documenting lessons learned, facilitating closure, preserving records and tools, releasing resources. Reward and recognize team members.

Decision-making follows a process. It begins with gathering data, and, to be useful, data have to be transferred and stored, either in a computerized database or in a file cabinet in someone's office. Then, they have to be retrieved where they can be analysed. In Chap. 8, geospatial techniques for data collection and analysis, is presented and can be used for this purpose.

Analysis leads to recommendations, to make a change or not. If the decision is to make a change, and if it is a good decision, value is created when that decision is implemented.

Indeed, project management and environmental management processesoverlap and interact throughout the entire project life cycle. For example, the scope of a project cannot be defined in the absence of some basic understanding of how to achieve a specific outcome (e.g., environmental protection, environmental conservation, or remediation of contaminated sites).

3.3 Project Management Versus Environmental Management

"Project management is like juggling three balls - time, cost, and quality within a defined scope; environmental management is like a troupe of circus performers standing in a sustainability circle, each juggling-three balls - people, prosperity, and planet, yet unable to hit the target"—Sholarin E.A.

Generally, management is defined as the act of getting people together to accomplish desired goals and objectives. It comprises of planning, organising, and controlling an organisation or a group of people as well as needed resources to accomplish a set goal. Resources may consist of people, finance, technology, material, equipment, etc.

Project management is the act of collaborating with people, using other required resources, such that a project is planned, organised, and controlled effectively to accomplish the project goals and objectives within the stipulated timeframe. Environmental management, on the other hand, is a term that can have different interpretations, (see, e.g., Wilson and Brant 1997; Thomas 2005). To most people, environmental management is synonymous to managing the environment; just like saying project management is same as managing a project. However, to people working in the field, the term may cover the detailed techniques, tools, or processes used for managing specific parts of the environment.

Environmental management is not separate from project management; it must be seen by all project management professionals as an integral part of their work at all stages of the project life cycle. However, some elements of environmental impact assessment (EIA), such as monitoring and auditing, could be an integral part of the design, construction, operation, and decommissioning phases of a project. In the past, the main tools for project appraisal were cost-benefit analysis (CBA) and net present value (NPV); both logical and quantitative methods for identifying whether or not a project was worth implementing. Many exploration and production projects, such as Sakhalin 2 liquified natural gas (LNG) projects in Russia, were assumed to have such overwhelming benefits that only the costs were assessed in order to determine which of the various alternative methods of achieving the project objectives was the most cost-effective.

It is now recognised that all projects will result in some unquantifiable costs and benefits, and therefore today these appraisal methods are supplemented by environmental impact analysis and assessment. By its nature, environmental impact assessment (EIA) requires a much more qualitative approach to project appraisal than cost-benefit analysis, although this is gradually changing as new methods for valuing environmental impacts, e.g., geospatial-based tools and techniques, discussed in Chap. 8, emerge and develop.

Wilson and Bryant (1997) define environmental management as a "multi-layered process associated with the interactions of state and non-state environmental managers with the environment and with each other." This definition points out that not all environmental management will lead to sustainable development. The definition provides little indication of what the outcome may be of environmental management. Environmental change is not always good. It is important to distinguish between environmental management, which is "unsustainable" and that which will lead towards sustainable development goals. The latter is what we refer to as environmental project management. It is based on the principles of sustainable development outlined in the World Commission of Environment and Development (WCED 1987, p. 37).

3.4 Incorporating Environmentalism into Project Management

There are many examples of projects undertaken to produce some deliverables with environmental implications. In fact, any project, since it uses resources, can be said to have environmental implications. This varies tremendously, based on scale and the direct impact on the environment. Many companies (e.g., Exxon Mobil, Shell BP, Chevron, Alcoa, etc.) are now incorporating environmental considerations into their thinking about the deliverables of their projects, and some are even integrating this thinking into the operation of that deliverable.

Environmentalism has been defined as "an advocacy for or work toward protecting the natural environment from destruction or pollution" (American Heritage Dictionary 2014). It means recognizing the planet's environmental problems and coming up with solutions (individually and collectively) that try to put them right. Although projects are supposed to "attain its objective and then terminate" (PMI 2013), project managers need to remember that their projects exist in a company's broader framework, because projects are "often utilized as a means of achieving an organization's strategic plan" (PMI 2013, p. 9). Project managers are responsible for ensuring success in terms of "product and project quality, timeliness, budget compliance, and degree of customer satisfaction" (PMI 2013, p 7). Only by understanding

	Knowledge Areas	Process Group				
		Initiating	Planning	Executing	Controlling	Closing
Environmental Management	Integration Mgmt	X	X	X	X	X
	Scope Mgmt		X		X	
	Time Mgmt		X		X	
	Cost Mgmt		X		X	
	Quality Mgmt		X	X	X	
	HR Mgmt		X	X		
	Communications Mgmt		X	X	X	
	Risk Mgmt		X		X	
	Procurement Mgmt		X	X	X	X
	Stakeholder Mgmt	X	X	X	X	

Adapted from PMBOK, 2013

Fig. 3.13 Project management framework with environmental-impacted knowledge areas indicated: The *circled items* represent the knowledge areas with strong environmental considerations

the goals and objectives of the project, can the project manager appropriately manage the scope, costs, risks, procurement and stakeholders (see Fig. 3.13).

Project managers need to look beyond the given project scope, cost, risks, procurement and stakeholder requirements to see if there are environmental considerations. Such "green" considerations could include the following:

- do we understand the environmental impact of our projects?
- what is the regulatory or legislative costs (e.g., cost of non-compliance)?
- what discount rate do we use to calculate future benefits and costs?
- what are the cost advantages and disadvantages of 'green design'?
- could the government change the rules in the future?
- are there advances in technology that will change the way we interact with the environment?
- where are the raw materials sources from? What happens to the material when the project/product has completed its life cycle (can it be re-used, recycled or recovered?)

In view of the above questions, project management must operate within a strategic context that balances economic viability, environmental soundness and social advancement (see Fig. 3.15). A project with straight-forward business goals should also incorporate environmental considerations throughout the project life cycle. The budgeting work packages must holistically account for environmental activities and establish the budget baseline appropriately.

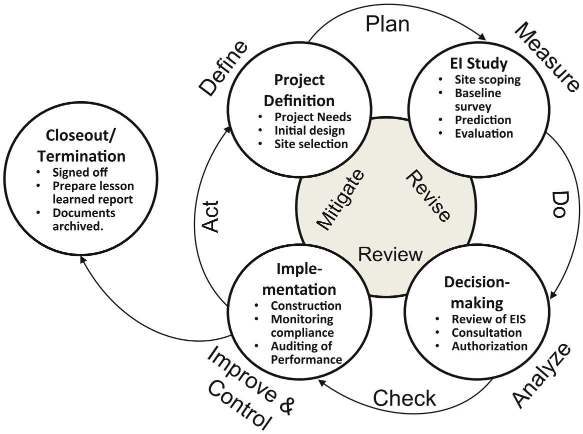


Fig. 3.14 Environmental project life cycle, incorporating the P-D-C-A and DMAIC methodology (after Petts and Eduljee 1994)

3.4.1 The Environmental Project Life Cycle

A project is, by definition, a unique and temporary undertaking, which means it has its own life cycle with distinct phases or structure. The structure makes it possible for a project manager to design an effective project management system (planning, implementation, and control systems) and provides some clear milestones to measure and monitor progress. The clarity provided by the project management structure enables performance reporting to take place at appropriate points in the process and keep everyone appraised of progress. An environmental project is often determined by the regulatory program, which is driving the project. The project management process, over the course of this life cycle, can be grouped into five sequential (sometimes overlapping) steps: scoping, planning, executing, reviewing, and accomplishing. These sequential steps can be further broken down into five distinct phases in time through which an environmental project passes: definition, environmental impact study, decision-making, implementation, and termination/close out. An environmental project life cycle incorporating the "Plan-Do-Check-Act" PCDA and "Define-Measure-Analyze-Improve-Control" (DMAIC) methodology (see Petts and Eduljee 1994) is shown in Fig. 3.14.

3.4.2 Environmental Project Phase Activities

A typical environmental project will have five distinct phases to it. Collectively, these are often referred to as *environmental project life cycle*. The life cycle of the environment continues, although its eco-systems may change, whereas projects are time-defined interruptions, i.e., *temporary endeavour*. The list below summarizes them in the context of environmental project management.

1. The **Initiation or Definition phase** is typified by a report or study to decide whether the problem is significant enough to justify an initiation of an environmental project (e.g., identify oil spill, industrial waste or gas releases that require further investigation; characterized nature, extent, and rate of release). The phase can be broken down into the following stages:

   - need and alternatives
   - initial design
   - site selection.

2. In the **Environmental Impact Study (EIS) phase**, more detailed environmental impact assessment (EIA) study is required in order to evaluate alternatives and decide the environmental protection, conservation or remediation strategy to adopt. By this point, the problem has been identified and a need has been established. The scoping of the project is based on thorough understanding of the issues and their implications. The phase includes the following stages:

   - site-specific scoping
   - baseline survey
   - prediction
   - evaluation
   - preparation of environmental impact study (EIS).

3. The **Decision-making phase** is the phase where the detailed requirements of the project are agreed upon. The understanding developed through detailed environmental impact study will enable professional judgments to be made about the likelihood of success. The phase can be broken down into the following stages:

   - review of environmental impact study
   - consultation
   - authorization and final design.

4. **Implementation phase**: Having decided what, if anything, needs to be done, this phase determines how it will be done and engages a range of internal and external expertise to implement developed strategy. This phase actually is where the project is switched on and it becomes alive. The phase include the following stages:

   - construction
   - monitoring of compliance and impacts
   - auditing of performance.

5. **Close-out/Operation phase** is, perhaps, where all the previous phases are delivered and the project evolves into an operation program of the organization and ceases to be a project. All documents are signed off and archived as lesson learned for future projects. It is now an operational program. Whenever another environmental problem is identified, a new project emerges and the life cycle starts up all over again.

3.4.3 *Environmental Project Management Triangle*

Project management is often summarised in a triangle (see Fig. 3.5). The three most important factors are time, cost and quality, commonly called the triple constraint. These form the vertices with scope as a central theme. This means projects must not exceed the provided budget, be within the scope, delivered on time and finally meet customer quality requirements.

An environmental project management triangle, with cost, time and scale is hereby proposed as the three vertices, and sustainability as the central them (see Fig. 3.15). Scale, discussed in Sect. 8.2, is an important metric that defines the level of detail of geospatial information that can be extracted from a map (see e.g., Awange and Kiema 2013), while space is that boundless extent in which objects and events occur and have relative position and direction (Britannica 2014).

The following four questions should be of major concern to an environmental project manager:

1. how long have I got?
2. how much can I spend?
3. what level of detail can I extract from a map scale?
4. what is the ultimate outcome I want to achieve from my project?

The four questions mentioned above relate to one of the fundamental concept of environmental project management: the triple constraints of time, space and scale that bounds the universe (environmental regulation/compliance) within which every environmental project must be accomplished.

Figure 3.15 is a pictorial representation of an environmental project management triangle. The figure shows that environmental project management involves the following elements;

- a temporary endeavor (environmental protection, conservation or remediation) undertaken to produce a sustainable outcome (product, service or result, that is economically viable, environmentally sound and socially acceptable),
- within the constraints of time/schedule, cost/space and quality/scale,
- within the constraints of people (societal needs, stakeholder requirements), planet (efficient exploitation of natural resources) and profit (improving economic prosperity through efficient use of organizational resources: human, materials, equipment, financial, information/technology, facilities).

The dimensions of geodata (time, scale and space), as shown in Fig. 3.15, represent the underlying concepts contextualized within the environmental project management framework shown in Fig. 5.1, on p. 97.

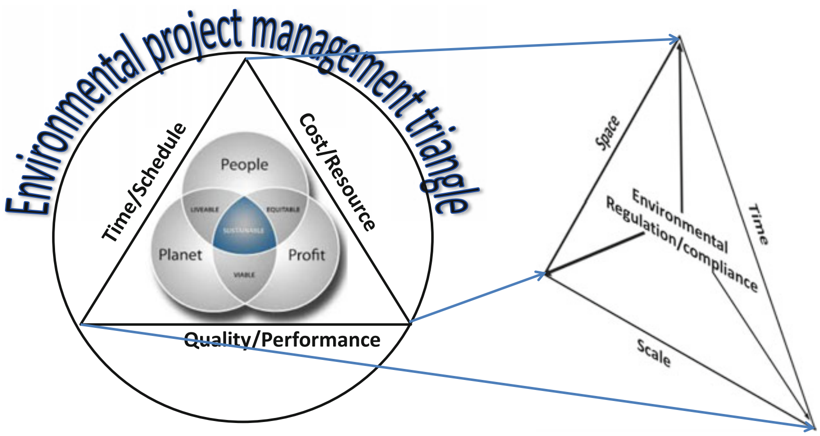


Fig. 3.15 Integrating sustainability thinking into EnvPM triangle: The figure shows the integration of project management triangle (cost, time and quality with sustainability as the central point), and geodata (space, time and scale with environmental compliance as the central point), forming an environmental project management triangle

3.5 Integrating Sustainability Thinking into Project Management

Sustainability is one of the most important challenges of our time (See e.g., Glenn and Gordon 1998; Jaafari 2007). How can we achieve economic prosperity and technological advancement, without compromising the life of future generations? Proactively, or reactively, companies are looking for ways to integrate ideas of sustainability in their marketing, corporate communication, annual reports, and in their actions (Holliday 2001). The balance between economic growth and social well-being has been around as a managerial challenge for over 150 years (Dyllick and Hockerts 2002). Also the concern for the wise use of natural resources and our planet emerged already many decades ago (see, e.g., Carson 1962). Meadow et al. (1972) warned that if the world's population and economy continue to grow at their current speed, our planet's natural resources would approach depletion. The warning fuelled a public debate, leading to the installation of the United Nation's World Commission on Environment and Development (WCED), otherwise known as "Brundtland Commission" (see WCED 1987). In its broadest sense, sustainability aims at promoting harmony among human beings, corporate organisations, and nature.

Sustainability is not a simple concept to define and there are a large number of interpretations (Epstein 2008; Pope et al. 2004; Robert et al. 1997; Munier 2005). Early development was largely influenced by Brundtland (1987) through the report "Our Common Future" and the definition of sustainable development. The report pointed out intra-generational development and inter-generational equity; and the needs of sound environment, just society, and healthy economy. In the last two decades since the 1992 Earth Summit, an increasing number of projects have built in sustainability considerations into project design and implementation.

Brundtland (1987) defines sustainable development as “the development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. The context in which Brundtland’s definition is embedded indicates that “needs” include a sound environment, a just society, and a healthy economy (Diesendorf 2000). One problem with the Bruntland’s definition is that it does not provide good day to day guidance for attempting to integrate sustainability into a company’s operations and/or projects. Sustainable development involves not just one but four complex interacting systems. It deals with a global economy that now spans every part of the world; it focuses on social interactions of trust, ethics, inequality, and social support networks in communities; it analyses the changes to complex Earth systems such as climate and ecosystems; and it studies the problem of governance, including the performance of governments and businesses (Sachs 2015).

A project has been defined as “a temporary undertaking that has a specific objective and a definite beginning and end, with the key focus often being the creation of a unique product or service” (Labuschagne and Brent 2004). Sustainability, however, has a long term orientation and this direct contrast with the short term nature of projects creates an imbalance that makes it challenging to integrate sustainability thinking into project management in a meaningful and measurable way.

Project management as an evolving academic discipline and professional practice is developing, and will continue to develop, in response to the needs of society. For instance, early days of modern project management focused on the efficiency of managing project. Now, focus has been changed to effective implementation of corporate strategy, which effected some organizational changes in the 1990s (Baccarini 1999). Shenhar and Dvir (2004) describe central concept of project management since 2000 as adaptation (one size does not fit all); strategic alignment (connect project management to governance); and globalization, e.g., off-shore projects.

Project sustainability is derived by considering the economic, social, and environmental impacts of a project, and by promoting local ownership and building local capacity (i.e., governance). Projects, as important business operations, have not escaped the 21st century challenge of ensuring sustainable development. Interest and efforts in integrating sustainable development (SD) in projects is growing yet still scant. Sustainable development, the process of balancing financial profitability interests of organizations with larger societal concerns for economic development, environmental safeguards, and satisfaction of societal needs in the short, medium, and long-term, is yet to be the standard practice in projects (see, e.g., Gareis et al. 2010; Silvius et al. 2010). It is helpful to think of sustainable development as a constantly evolving process, as opposed to sustainability, which is an outcome. This is an ideal development efforts, which is constantly changing, based on the ethics and values of stakeholders. Therefore, sustainable development is a stakeholder-focused process that projects must enter (Bagheri and Hjorth 2007, p. 84).

Badiru (2010) defines project sustainability as “the ability to sustain and maintain a process or object at a desirable level of utility”. The concept of sustainability applies to all aspects of project requirements, embracing technical, financial, and managerial needs. In the context of environmental project management, sustainability is nothing more than prudent resource utilization. Project sustainability is as much a need as the traditional components of project management that span planning, organizing, scheduling and control. Proactive pursuit of the best practices of sustainability can pave the way for project success on a global scale. In addition to people, process and technology issues, there are project implementation issues. In terms of performance, if better policy is required, it can be developed; if technological advancement is needed, there are enough capabilities to achieve it (Badiru 2010). The items that often are beyond reach relate to environmental management issues.

Project sustainability implies that sustainability exists in all phases related to environmental project management system. Within the system, an environmental project is broken down into a number of distinct phases with clear sustainability objectives and deliverables. At the completion of each phase is a decision point to decide if the project is ready to move into the next phase—if not, it is reassessed or abandoned. Thus, the main focus should be on project sustainability. Project exists in a relatively turbulent environment and change is the purpose of the project itself and uncertainty is inherent in the objectives of that project.

Integrating the concepts of sustainability into corporate strategy, however, suggests that not just the process of delivering the project is considered, but also the content of the project itself (Silvius and Tharp 2010). These include the environmental project management methods such as ISO 14001 environmental management systems, Plan-Do-Check-Act (PDCA) cycle, the six sigma Define-Measure-Analyze-Improve-Control (DMAIC) system, environmental impact assessment (EIA), triple bottom line principle, cleaner production, eco-efficiency and life cycle assessment. These elements will be elaborated in Chap. 5.

3.6 Concluding Remarks

This chapter draws a distinction between management of projects and management of the environment. Whereas the first concept applies a traditional (triple constraints), process-based, agile, PMBoK, resource-optimization and benefits realisation approach to creating a unique product, services or result; the second is concerned with the implementation of the environmental management system (EMS 140001), environmental impact assessment (EIA) and life cycle assessment (LCA). The two approaches can be seen as extremes on a spectrum. Modern project management literature is dominated by the “plan-do-check-act” approach. In this chapter, we point to implications of choosing same management approach for environmental protection and/or remediation projects. This includes developing a more comprehensive understanding of the environment from sustainability perspective. The core difference between the approaches lies in the underpinning values, and not so much in the processes and methods. Still some methods are more suitable than others to incorporate a management of environmental projects. Regardless of approach, a comprehensive environmental project management process consists of five sub processes: project definition, environmental impact study, decision-making, implementation, and close-out.

In this chapter, various facets of project organisation structures are discussed. These include the traditional/functional organisation structure, matrix organisation structure, and organisation structure with project management as staff function as well as their merits and demerits. Under project-based organisation structure, diverse aspects such as project environment, selection of project manager, project staffing process, project office and functional team members have been discussed. Finally, the need to integrate sustainability thinking into organisation project strategy was stressed.

References

Allianz (2014) Working in a global matrix organisation. www.agcs.allianz.com. Accessed 23 Sep 2014

Awange JL, Kiema JBK (2013) Environmental geoinformatics, monitoring and management. Solving algebraic computational problems in geodesy and geoinformatics. Springer, Berlin, Springer, Berlin

Baccarini D (1999) History of project management. Curtin University of Technology, New South Wales

Badiru AB (2008) Industrial project management: concepts, tools and techniques. CRC Press, Boca Raton

Badiru AB (2010) The many languages of sustainability: IEs should push for better resource utilization across all fields. J Ind Eng 42(11):30–34

Badiru AB (2012) Project management: systems, principles and applications. Taylor and Francis Group, CRC Press, Boca Raton

Badiru AB, Osisanya SO (2013) Project management for the oil and gas industry: a world system approach. CRC Press, Boca Raton, Business & Economics 781 p

Bagheri A, Hjorth P (2007) Planning for sustainable development: a paradigm shift towards a process-based approach. J Sustain Dev 15(2):83–89

Belbin RM (1993) Team roles at work. Butterworth, Oxford

Boddy D, Buchanan D (1992) Take the lead: interpersonal skills for project managers. Prentice Hall, London

Britannica (2014). http://www.britannica.com/ Accessed 30 Mar 2014

Brundtland GH (1987) Our common future. Oxford University Press, Oxford

Burke R, Barron S (2014) Project management leadership: building creative teams. Wiley, New York 384 p

Butler CJ, Chinowsky PS (2006) Emotional intelligence and leadership behaviour in construction executives. J Manage Eng 22(3):119–125

Carson R (1962) Silent spring. Houghton Miflin, Boston

Clemen RT (1991) Making hard decisions. PWS-Kent Publishing Company, Boston

Crawford L (2007) Global body of project management knowledge and standards. In: Morris G, Pinto J (eds) The Wiley guide to managing projects. Wiley, New York

Diesendorf M (2000) Sustainability and sustainable development. In: Dunphy D, Benveniste J, Griffiths A, Sutton P (eds) Sustainability: the corporate challenge of the 21st century. Allen and Unwin, Sydney, pp 19–37

Dyllick T, Hockerts K (2002) Beyond the business case for corporate sustainability. Bus Strategy Environ 11:130–141. doi:10.1002/bse.323

Environmentalism (n.d.) In: American Heritage Dictionary (online). http://ahdictionary.com/word/search.html?q=environmentalism. Accessed 28 Aug 2014

Epstein MJ (2008) Making sustainability work: best practices in managing and measuring corporate social, environmental, and economic impacts. Berrett-Koehler Publishers Inc, San Francisco

Fleming QW, Koppelman JM (2000) Earned value project management, 2nd edn. Project Management Institute, Upper Dalby

Gareis R, Huemann M, Martinuzzi A (2010) Relating sustainable development and project management: a conceptual model. In: Paper presented at the PMI Research and education conference. New York

Glenn JC, Gordon TJ (1998) State of the future: issues and opportunities. American council for the United Nations University, Washington

Grinnell SK, Apple HP (1975) When two bosses are better than one. Mach Des, pp 84–87

Harrison FL, Lock D (2004) Advanced project management: a structured approach. Gower Publishing Ltd, Guildford, Business & Economics 315 p

Holliday C (2001) Sustainable growth, the Dupont way. Harv Bus Rev 79:129–134

Hulett D (2012) Integrated cost-schedule risk analysis. Gower Publishing Ltd, Guildford, Business & Economics 240 p

ISO, TMB (2009) ISO 31000:2009, risk management - principles and guidelines. Multiple, distributed through American National Standards Institute (ANSI) (Reprint)

ISO (2012) International Organization for Standardization. [Geneva: ISO.]. ISO, 21500, 2012

Jaafari A (2007) Thinking of sustainability as a dimension of managerial competency. PM World Today 9(9)

Kahneman D, Tversky A (1979) Prospect theory: an analysis of decision under risk. Econometrica 47:263–291

Kerzner H (1982) Project management for executives. Van Nostrand Reinhold Company Inc., New York 716 p

Kerzner H (2004) Advanced project management: best practices on implementation. Wiley, New York 847 p

Kerzner H (2010) Project management: systems approach to planning, scheduling, and controlling, 11th edn. Wiley, Hoboken

Kipling R (1902) I keep six honest serving men. In: Kipling R (ed) The elephant's child (Just so stories). www.kipling.org.uk/poems_serving.htm. Accessed 19 Dec 2013

Labuschagne C, Brent AC (2004) Sustainable project life cycle management: aligning project management methodologies with the principles of sustainable development. In: Paper presented at the PMSA International Conference, Johannesburg, South Africa

Lock D (2007) Project management, 9th edn. Gower Publishing Limited, Aldershot

Marler T (1994) Introduction to oil and gas project management. PennWell Publishing Company, Oklahoma

Meadows DH, Meadows DL, Randers J, Bedhrens WW III (1972) The limits to growth: a report for the club of Rome's project on the predicament of mankind. Universe Books, New York

Muller R, Turner JR (2012) Project-oriented leadership. Gower Publishing, Aldershot Ltd, Business & Economics 110 p

Munier N (2005) Introduction to sustainability: road to a better future. Springer, Berlin

NORSOK (2002) Norsok S-012 Health, safety and environment (HSE) in Construction-Related Activities (Rev 2, Aug 2002), Multiple. Distributed through Standard.no (Reprint)

Northouse PG (2007) Leadership theory and practice, 3rd edn. Sage, Thousand Oaks

Petts J, Eduljee G (1994) Environmental impact assessment for waste treatment and disposal facilities. John Wiley, Chichester 342 p

PMI (2013) A guide to the project management body of knowledge (PMBOK guide), 5th edn. Project Management Institute, Newtown Square

Pochron RS (2009) A leadership journey: personal reflections from the school of hard knocks. Integr Rev 5(2):265–272

Pope J, Annandale D, Morrison-Saunders A (2004) Conceptualising sustainability assessment. Environ Impact Assess Rev 24:595–616. doi:10.1016/j.eiar.2004.03.001

Robert K-H, Daly H, Hawken P, Holmberg J (1997) A compass for sustainable development. Int J Sustain Dev World Ecol 4:79–92

Sachs JD (2015) The age of sustainable development. Columbia University Press, New York

Schuyler J, Newendorp P (2000) Decision analysis for petroleum exploration, 2nd edn. Planning Press, Aurora

Shenhar AJ, Dvir D (2004) Project management evolution: past history and future research directions. In: Slevin, DP, Cleland, DI, Pinto JK (eds) Innovations: project management research. Project Management Institute, pp 57–64

Sholarin EA (2007) Integrated project management for hydrocarbon portfolio analysis and optimization. J Pet Technol 59:2

Silvius AJG, Tharp J (eds) (2010) Survival and sustainability as challenges for projects. Zurich, Switzerland

Silvius AJG, van den Brink J, Khler A, (2010) The concept of sustainabilityand its application to project management. In: Paper presented at the IPMA international expert seminar 2010 - Survival and sustainability as challenges forprojects. Zurich, Switzerland

Sinek S (2009a) Start with why: how great leaders inspire everyone to take action. Penguin Group, New York 246 p

Sinek S (2009b) Start with why: how great leaders inspire everyone to take action. Penguin Group, New York 246 p

Slater R (2001) Jack Welch, and the GE way. McGraw-Hill, New York, p 29

Thomas IG (2005) Environmental management processes and practices for Australia. The Federation Press, Annandale 360 p

Turner JR (ed) (2009) The handbook of project-based management: leading strategic change in organizations, 3rd edn. McGraw-Hill, New York

UN (1992) Agenda 21: program of action for sustainable development. United Nations, New York

Vaidyanathan G (2013) Project management: process, technology, and practice. Pearson, Upper Saddle River

Wheatley MJ (1999) Leadership and the new science: discovering order in a chaotic world. Berret-Koehler Publishers, San Francisco, Business and economics 197 p

Wideman RM (1991) A framework for project and program management integration, vol 1. The PMBOK handbook series, Project Management Institute, Drexel Hill

Wilson GA, Brant RL (1997) Environmental management: new directions for the twenty-first century. University College London Press, London

WCED (1987) World commission on environment and development: our common future (the Brundtland report). Oxford University Press, Oxford

Chapter 4
Essential Project Management Functions

A functional approach to project management describes a mode of action by which an objective or goal is fulfilled. The project Managem ent Institute (PMI), in its PMBoK guide, 5th edition, identified ten distinct functional modes (knowledge areas) currently used internationally in project management best practice, by which a project objective can be achieved. The knowledge areas, which constitute the essential functional areas that embody the practice of project management and their meanings are summarised below (PMI 2013):

1. Integration management: What project plans are needed?
2. Scope management: What work should be done as part of the project? How will the scope be verified?
3. Time management: How long should it take to complete the project?
4. Cost management: What are the cost implications?
5. Quality management: Are the technical standards being met?
6. Risk management: What are the road blocks; what is the likelihood of success?
7. Human resources management: Who do I need for my project?
8. Procurement management: How do I get what I need?
9. Communications management: How do we collaborate to work together?
10. Stakeholder management: Who or which groups have a vested interest in my project?

Several topics covered in this book address many of the key elements embodied in the knowledge areas. These knowledge areas are grouped into the following functions;

1. coordinating function,
2. planning and controlling functions (organising, planning/scheduling, monitoring and controlling), and
3. facilitating functions (leading, executing, communicating, outsourcing, closing and delivery).

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4.1 Coordinating Function: Project Integration Management

Coordinating function consist of only one knowledge area: the project integration management.

Project integration management describes the processes and activities needed to identify, define, combine, unify, and coordinate the various processes and project management activities within project management process groups (PMI 2013). It is the knowledge area that integrates all important aspects of a project and makes them visible and manageable.

Project integration management involves coordinating all other nine knowledge areas through the entire project plan. Of course, other knowledge areas need to be mastered to ensure project success. These are the results or deliverables produced by the project team, the time and cost dimension, the handling of risks, the people in the project, the communication and collaboration between them and finally the coordination of several project phases or sub-projects. The integration of other nine knowledge areas in a coherent planning methodology, their handling and display in a single planning document enables a considerable improvement of project performance. While tools and techniques used in project management today only covers 3 or 4 dimensions (scope, time, cost and quality), all other knowledge areas must be managed simultaneously in order to achieve a good outcome.

4.2 Planning and Controlling Functions

Planning and controlling functions include the scope, time, cost and quality knowledge areas described in the PMBoK guide. These functions are known as the four core functions of project management (PMI 2013). The functions include organising, planning, scheduling, monitoring, and controlling elements of project activities. These elements are integrated with one another within the project life cycle and form a basis against which the success of a project is determined.

4.2.1 Scope Management

A project scope is everything about a project—work content as well as expected outcomes. Project scope consists of naming all activities to be performed, the resources consumed, and the end products that is expected, including quality standards. Scope includes a project's goals, constraints, and limitations (Pinto 2013). Scope management describes the processes required to ensure that the project includes all the work required, and only the work required to complete it successfully (PMI 2013). During the planning phase of a project, scope management process involves collecting requirements from stakeholders and then using them to develop a project's scope using the statement of work (SoW), work breakdown structure (WBS), cost breakdown structure (CBS), risk breakdown structure (RBS), organization breakdown structure (OBS), and responsibility assignment matrix (RAM) to produce a unique product, service, or result.

4.2.2 Time Management and Scheduling

"Time is a sort of river of passing events, and strong is its current; no sooner is a thing brought to sight than it is swept by and another takes its place, and this too will be swept away."—Marcus Aurelius

One of the characteristics of a project is that it has an agreed start and finish time by which a specified objective must be accomplished, which is to say that the time available for completion is limited. Hence, it is very crucial that a project must be carefully planned, scheduled, and monitored if it is to be completed within the time frame provided by the customer. Time is considered to be part of the measuring system used to sequence events, to compare the durations of events and the intervals between them, and to quantify rates of change such as the motions of objects (IEP 2014). Time is the essence of managing all projects. It can also be defined as a limited, non-recyclable commodity (Badiru 2012). More about time, as a crucial component of a project management triangle (time-cost-quality constraints), has already been discussed in Chap. 2 and also in Sect. 9.2 under the geospatial dimension of space, time and scale.

4.2.3 Cost Management and Budgeting

Cost management is extremely important for running a successful project. The management of costs, in many ways, reflects the project organization's strategic goals, mission statement, and business plan. Cost accounting and cost control serve as the chief mechanisms for identifying and maintaining control over project costs (Pinto 2013). Project cost management describes the processes involved in estimating, budgeting, and controlling costs so that the project can be completed within the approved budget (PMI 2013). The cost is based on the types and quantities of resources required for each activity. A true budget is derived by summarising the cost estimates of all project activities and rolling them upward using the cost breakdown structure (CBS) and cost estimating methods.

4.2.4 Quality and Performance Management

The fourth and last core function of project management is the project quality management. For a project to be considered successful, the project management processes must align with the quality standards and strategy of the organisation executing the project. Throughout the project life cycle, quality requirements must be defined and planned, quality assurance tests conducted according to standards, monitored, and controlled.

4.3 Facilitating Functions

In addition to the core functions described in the previous section, project management involves five *facilitating functions*, which include: risk, human resources, contract/procurement, communication, and stakeholder management. They are called *facilitating functions*, because they are the means through which the objectives of the core (basic) functions are achieved (Wideman 1991).

4.3.1 Risk and Uncertainty Management

Before a project is started, a plan is prepared based on certain assumptions and estimates. It is important to document these assumptions, because they will influence the development of the project budget, schedule, and work scope. A project is based on a unique set of tasks and estimates of how long each task should take, various resources and assumptions about the availability and capability of those resources, and the estimates of the costs associated with the resources. This combination of assumptions and estimates causes a degree of uncertainty that the project objective will be completely accomplished. Uncertainty is, therefore, risk with no clear possible outcome or consequence. For example, it is possible to have a vague awareness of demons lurking out there. Even possible to be acutely concerned about them. However, there is no real idea how many of them are or when they mighty strike. Risk, on the other hand, is something that can be 'priced'. It provides the answer to three key questions: what can go wrong; how likely is it; and what are the consequences? (Kaplan and Garrick 1981).

Wideman (1998) defines risk as an "estimate of the probability of loss from a large population of unwanted circumstances". For example, the project scope may be accomplished by the target date, but the final cost may be much higher than anticipated because of low initial estimates for the cost of certain resources. As the project proceeds, some of the assumptions will be refined or replaced with factual information. Consequently, it is prudent to mitigate the possibility that requirements will not be met by reducing the risk without compromising overall project objectives.

Risk management is well established in the fields of banking, insurance and engineering as a management tool for dealing with uncertainty (Morris and Therivel 2009). It is also well used as a tool for improving occupational safety and setting priorities for the allocation of resources (see, e.g., O'Toole 2002; Steenbergen et al. 2013). Risk assessment and management as applied to environmental and ecological issues is a rapidly growing discipline within its own right (see e.g., Morris and Therivel 2009). There is now a wealth of publications, which range from the provision of guiding principles set by governments for public domain risk analysis (e.g. ISO 2009; USEPA 1992) to handbooks, which prescribe more detailed approaches to particular aspects of environmental risk assessment (see e.g., Calow 1998).

4.3.2 Human Resources and Interface Management

Projects of all types require people of different skills, knowledge, and abilities. This is the function of project human resources management. Probably the most common type of project constraint revolves around the availability of human resources to perform the project (Pinto 2013). The human resources are often formed into a project team and the structure changes in accordance to the project phase and the skill requirements. A responsibility assignment matrix (RAM), resource histogram, and resource leveling heuristics are the tools used for identifying the roles and responsibilities of various team members as well as making the best use of the available human resources. In order to improve the productivity of project team members, regular training and workshops need to be provided throughout the project life cycle.

The basic concept of interface management is the situation or location where independent work areas, organizations, people or systems meet, work or communicate with one another. The traditional ways of performing and managing projects is continuously facing unprecedented challenges. The growing competition in the industry is forcing companies to rethink their project management processes for improving productivity, quality, and efficiency. In the environmental sector, the large project complexities and uncertainties make it harder to be managed and controlled.

In order to be successful, industrial projects must manage interfaces between different work packages, disciplines, and people. As a project's size, geographic distribution, and number of participants increase so do the number and scope of interfaces involved. Without proactive and consistent control over these interfaces, project risk accelerates and the potential for project delays, cost overruns, and other negative outcomes are increased.

4.3.3 Communications and Information Management

Project communications management centers on determining who needs what information and when, and then produces the plan to provide the needed information. Communications management includes generating, collecting, disseminating, and storing information.

Communication is the key link between people, ideas, and information. It centers on who needs what information and when do they need it? What good is information if no one can find it? Information management system allows for fast and accurate access to project information. It can be a simple manual filing system, an advanced database of information storage, or a robust project management software suite. Whatever the approach, the information must be accessible, organized, and secure.

One of the main reasons why projects often take longer than planned and with disappointing results is due to poor communication and information management. When using traditional project planning techniques, time aspect of a project is being optimized by taking into account dependencies and other constraints. Experienced project managers know that this is not enough. Many other aspects, such as human resources, risks, costs and budgets, deliverables, stakeholders, and information resources need to be managed as well. In fact, using Gantt chart as a project planning tool can be counter-productive, because it is difficult to see the "big picture" when your computer screen shows you the time dimension so very nicely. There are many different possibilities for information to be lost, messages to be skewed, and progress hindered. This is why communication management is considered the most important knowledge area in project management (PMI 2013). It is fundamentally different from other knowledge areas.

Project communications management uses communications channels to determine the distinct paths of communication that is possible between the project manager and other stakeholders for information distribution path. As the number of stakeholders increases, the complexity of communications increases because there are more communications channels or pathways through which people can communicate.

The project management institute (PMI) has provided a simple formula, which can be used to determine the number of communications channels as the number of stakeholders in a project increases. This can be calculated as follows:

$$C = N(N - 1)/2, \tag{4.1}$$

where:

- C is the communication channels, and
- N represents the number of stakeholders that require project information.

For example, six key stakeholders and roles they perform on a project is shown in Table 4.1.

Using Table 4.1 as a reference, a project has 6 stakeholders (Project Manager plus 5 others), the formula would produce a total of 15 communication channels, i.e.,

$$C = 6 \times (6 - 1)/2. \tag{4.2}$$

The total number of communication channels among 6 stakeholders is illustrated graphically in Fig. 4.1.

Rather than showing the timeline, milestones, resource histogram and S-Curve, project communication channels, Fig. 4.1 shows an illustration of who is (or should be) communicating with who, and how produced information flows between people, departments, and even organisations to achieve project goals. Indeed, this is what any project team should be focusing on before worrying about scope, time, cost, and quality.

Table 4.1 Key project stakeholders and their roles

Stakeholder	Roles performed
1. Project manager (PM)	• Person responsible for the management of the project on a daily basis
2. Project team members (S1)	• Responsible for performing project tasks
	• Provides and applies technical skills
3. Customer/client (S2)	• Person or organisation that 'own' the project
4. Project sponsor (S3)	• Initiates or champions the project
	• Wins the support of the most senior members in the company
5. Supplier/contractors (S4)	• Provides logistical support
	• Deliver equipment, materials and services to the project as required
6. The user (S5)	• The person, group or organisation that will make use of the project product

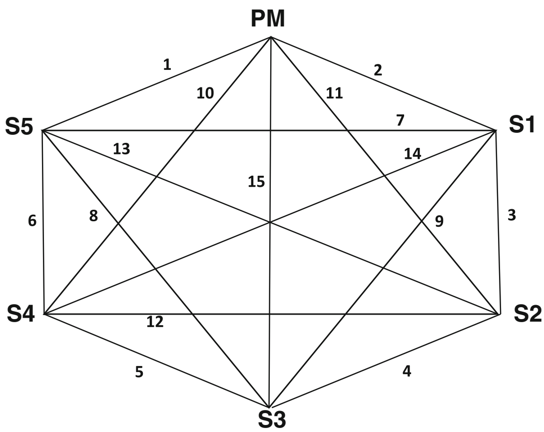

Fig. 4.1 Number of stakeholders and communications channels (6 people, 15 communications channels)

Knowing complexity of communication channel gives a better control over information distribution and hence better communication planning and good project outcome.

4.3.4 *Contract and Procurement Management*

It is common today for companies to procure major portions of their projects from other companies. Some projects buy as much as 80 % of their project scope from other companies (see, e.g., Fleming 2003). Project procurement management includes the processes necessary to purchase or acquire products, services, or results needed from outside the project team (PMI 2013). Procurement management includes administering contracts and change control process to manage contracts or purchase orders. Projects routinely require materials, equipments, consultants, training, and many other goods and services, which may be outsourced to people outside the organisation. These people or organisation are called the suppliers, contractors, subcontractors or vendors. A make-or-buy technique is used to determine whether a particular task can be accomplished by the project team or must be procured from outside sources. Procurement or contract management involves getting work done by people outside the project team.

4.3.5 Stakeholder and Requirements Management

One of the first steps in project management planning is the identification of stakeholders. In order to accomplish this, it is pertinent to understand and identify what a stakeholder is. According to the PMBoK guide, a stakeholder is a person or organisation that are actively involved in the project, or whose interests may be positively or negatively affected by the execution or completion of the project (PMI 2013). Stakeholders can be individuals working on a project, groups of people or organizations, or even segments of a population. A stakeholder may be actively involved in a projects work, affected by the project's outcome, or in a position to affect the project's success. Stakeholders can be an internal part of a project's organization, or external, such as customers, creditors, unions, or members of a community. The tool that can be used for managing stakeholder effectively is called *stakeholder analysis*. This is discussed in detail in Chap. 5.

Another important aspect of project management functions is the requirements management plan. Requirements definition, a critical factor in project success, is essentially an iterative conversation between the customer and the project team to determine what the customer is asking for and how the project team can deliver it. As the project team develops its approach, it will inevitably suggest options to the customer, all of which have cost, schedule or performance implications.

Scope creep, miscommunications, disengaged project sponsors and stakeholder disinterest in a project are problems that can, if not properly managed, cause a project or program to sink. These problems involve or impact requirements. Requirement management plan establishes the requirements, requirement types, requirement attributes, and traceability of a project in order to manage project requirements. Requirements management involves initiating, implementing, and maintaining an agreement between a project sponsor (or customer) and project manager on both technical and non-technical requirements. The agreement forms the basis for a project scope, which will eventually be used in estimating, planning, performing, and tracking project activities throughout the project (Vaidyanathan 2013).

Project requirements management is the process of identifying, defining, documenting, and managing the solution a successful project must deliver. The PMBoK Guide, fifth edition, describes *requirements* as "conditions or capabilities that must be met by the project or present in the product, service or result to satisfy an agreement

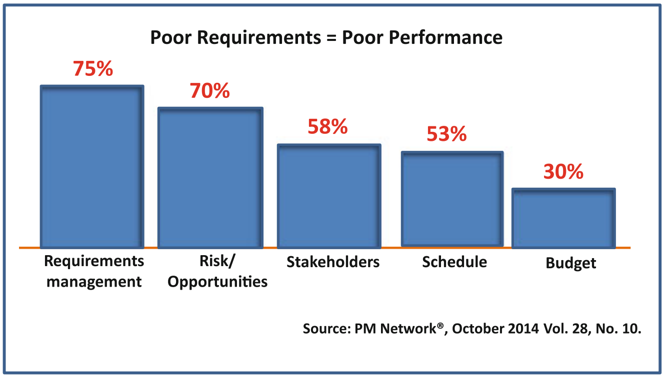

Fig. 4.2 Unsuccessful projects where poor requirements management is the primary cause of project failure

or other formally imposed specification. The process includes the quantified and documented needs and expectations of the sponsor, customer, and other stakeholders. These requirements need to be elicited, analysed, and recorded in enough detail to be included in the scope baseline and be measured once the project execution begins" (PMI 2013).

When inadequate or poor communication is a primary cause of project failure, 75 % of organizations report, as shown in Fig. 4.2, that the issue negatively affects requirements management more than any other area of their projects (PMI 2014).

In a survey about "the current state of requirements management and its impact on projects and programs", conducted by the project management institute (PMI) in October, 2014, involving more than 2000 project management practitioners and business analysts, it was revealed that nearly half of unsuccessful projects fail to meet goals due to poor requirements management. For every dollar spent on projects and programs, 5.1 % is wasted due to poor requirements management. This amount to US$51 million wasted for every US$1 billion spent (PMI 2014).

4.4 Concluding Remarks

This chapter provides an overview of the essential project management functions and boundaries. This is followed by an examination of each function, which itself is correlated with ten project management knowledge areas identified by the project management institute (PMI). The chapter concludes with the analysis of each knowledge area and their relevance to environmental project management

References

Badiru AB (2012) Project management: systems, principles and applications. Taylor and Francis Group, CRC Press, Boca Raton

Calow P (1998) Handbook of environmental risk assessment and management. Blackwell Science, Oxford

Fleming QW (2003) Procurement management: contracting, subcontracting, teaming. FMC Press, Tustin

IEP (2014) Internet encyclopedia of philosophy www.iep.utm.edu Accessed on 13/03/2014

ISO (2009) ISO 31000:2009, risk management - principles and guidelines. Multiple, distributed through American National Standards Institute (ANSI) (Reprint)

Kaplan S, Garrick B (1981) On the quantitative definition of risk. Risk Anal 1:1–27

Morris P, Therivel R (2009) Methods of environmental impact assessment, 3rd edn, Routledge, 576 p

O'Toole M (2002) The relationship between employees' perceptions of safety and organizational culture. J Saf Res 33:231–243

Pinto JK (2013) Project management: achieving competitive advantage, Pearson, 3rd edn

PMI (2000) In: Project management research at the turn of the millennium: Proceedings of PMI research conference, Accessed 21–24 June 2000, Paris, France

PMI (2013) A guide to the project management body of knowledge (PMBOK guide), 5th edn. Project Management Institute, Newtown Square

PMI (2014) Requirements management? required for success: a few findings from PMI's pulse of the profession in-depth report, PM network, Oct 2014, vol 28(10)

Steenbergen RDJM, Gelder PHAJM, Miraglia S, Vrouwenvelder ACWM (2013) Safety, reliability and risk analysis: beyond the horizon. CRC Press, 18 Sep 2013, Technology & Engineering, 758 p

USEPA (1992) United States Environmental Protection Agency. Framework for ecological risk assessment, Risk Assessment Forum, Report EPA/630/R-92/001. Washington, EPA

Vaidyanathan G (2013) Project management: process, technology, and practice, Pearson

Wideman RM (1991) A framework for project and program management integration., The PMBOK handbook SeriesProject Management Institute, Drexel Hill

Wideman RM (1998) Project risk management. In: Pinto JK (eds) The project management institute project management handbook, Jossey-Bass Publishers and Project Management Institute

Chapter 5
Broad Framework for Environmental Project Management

It is my opinion that everything must be based on a simple idea. This idea, once we have finally discovered it, will be so compelling, so beautiful, that we will say to one another, yes, how could it have been any different.

—John Archibald Wheeler

5.1 Introductory Remarks

Today, organisations want to embed sustainable, environmental thinking into the way they reason, behave, and work. They want to avoid superficial "green-wash". They want to make a difference. They also want an environmental reputation, but one that comes from their values, behaviours, and culture, rather than simple claims of corporate environmental responsibility (CER). They want to be able to demonstrate their environmental credentials, which can make a significant impact on how customers perceive the organisation and how markets and investors value the organisation. It is important to the people who work there as well.

Sustainable development is a concept that forms the basis of environmental policy and environmental management. To help give sustainability a focus, the idea of developing measures of sustainability should be pursued through the framework of the triple bottom-line, eco-efficiency and cleaner production (Thomas 2007).

5.2 Developing an Environmental Project Management Framework

"Though no one can go back and make a brand new start, anyone can start from now and make a brand new ending" (Carl Bard—1907–1978).

We believe that the process of discovering and inventing a new project management system that will inhabit the twenty-first century has just begun. To be responsible project managers and environmental engineers, we need the courage to let go of the

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old world, to relinquish most of what we have cherished, to abandon our interpretations about what does and doesn't work. We must learn to see the world a new.

Environmental project management (EnvPM) comes with a unique set of challenges that include how to incorporate environmental impact perspective into project strategy. The challenges also include how to capture, measure and manage environmental impact on project planning documents. Underlining the specific issues involved in various environmental projects, we present in this chapter a broad framework for managing environmental protection and remediation of contaminated sites. The framework is being developed to provide practical guidance to practitioners as well as regulators in the areas of environmental project management. In compliance with environmental policy, a public consultation program should be designed in order to enable all stakeholders provide feedback on the developed framework. The consultation process will ensure widely supported framework for environmental project management.

Purpose and Desired Outcomes of Environmental Project Management Framework

The purpose of the developed Environmental Project Management Framework (EPMF) is to:

- establish a consistent approach to managing environmental protection, contamination and remediation projects;
- provide practical procedural guidance to environmental project management professionals;
- educate and inform government, industry and the community about the environmental issues and how the methodologies and processes discussed in the book can be applied for effective environmental management.

The desired outcomes of the developed Environmental Project Management Framework are to:

- protect human health and the environment;
- facilitate more effective and efficient environmental monitoring and remediation of contaminated sites; and
- provide net social benefit for people and the community.

The adoption of environmental project management framework as shown in Fig. 5.1 has given birth to a new concept of *sustainable environmental project management*, which provides context for corporate environmental compliance, environmental management, and environmental project planning and control system. The connections between these elements are represented in form of hierarchical steps, the uppermost layer being the environmental project management methodology, followed by environmental project management tools and the principles applied to achieve a sustainable environmental project management.

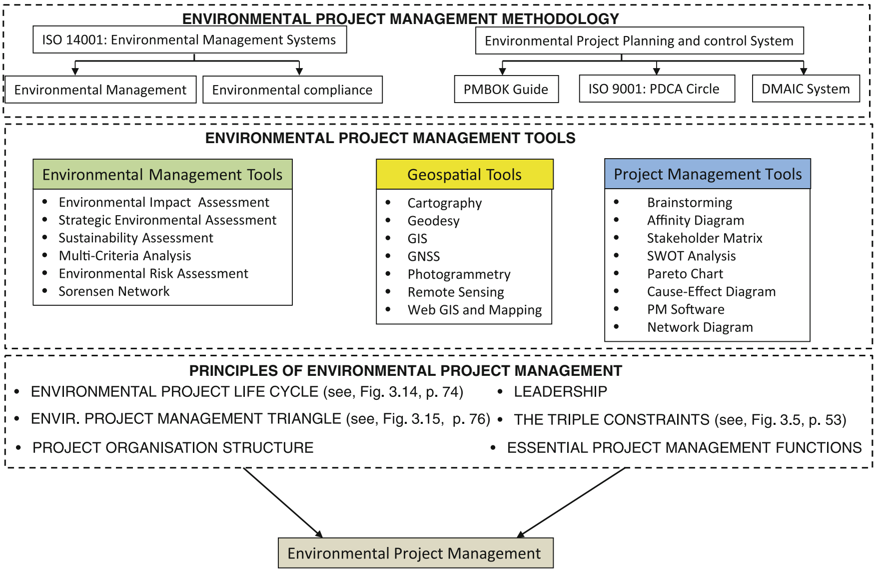


Fig. 5.1 Environmental project management framework

Figure 5.1 is a representation of the way in which ISO 14001: Environmental management systems, the PMBoK guide, ISO 9001: Plan-Do-Check-Act (PDCA) circle, the Define-Measure-Analyse-Improve-Control (DMAIC) system, the associated tools and processes relate to environmental project management.

Environmental project management framework (EPMF) is an overarching strategy that can be used to translate the commitments and measures contained in the draft environmental impact statement (EIS) into the project planning documents, engineering designs, contract documents, and the day-to-day business operation. The framework should be reviewed and modified to ensure that the environmental obligations associated with continuing the existing activities and establishing new activities are adequately managed. Subsequent sections will involve discussions on each components of the framework.

5.3 Environmental Project Management Methodology

Saladis and Kerzner (2011) define methodology as "a system of practices, techniques, procedures, and rules used by those who work in a discipline." Establishing a methodology and ensuring its consistent use provides many benefits including consistency, greater predictability of outcomes, and better management of the environment.

The environmental management system (EMS), the PMBOK Guide, the PDCA circle and the DMAIC system are methodologies that provide a basis for developing an organised approach to managing an environmental project. The processes, policies and procedures can be used to create a framework for managing environmental projects in a consistent manner that is acceptable for use by all business units and work entities within an organisation.

5.3.1 ISO 14001 Environmental Management System

Environmental management system (EMS) is a methodology that has developed over the past decade as organisations keep on looking for a new way of dealing with environmental issues, that is, for a new approach that fall somewhere between the free market (economic policy instrument) and conventional regulation (command and control policy instrument). Many firms pursue ISO 14001 certification in response to peer pressure (Clark 1999) in order to improve risk management and lower their liabilities (Graff 1997) harmonize standards with ISO 9000 (Litskas 1999), reduce inspection frequency and improve bottom line performance by enhancing internal efficiencies (Clark 1999; Graff 1997; Litskas 1999; Vastag et al. 1996a, b).

Currently, many organisations have recognised that meeting the regulatory requirements was not adequate for staying in the competition and have now turned their efforts to pollution prevention and monitoring for efficient operations (Hoffman 1994; Watson and Emery 2004; Yosie and Herbst 1996). EMS basically involves the establishment of an environmental plan, the creation of goals to reduce environmental impacts, the implementation of appropriate actions, and some form of internal assessment or monitoring.

The general basis for an EMS is to write how a task with an environmental impact is to be done, do the task as it is written, and check periodically to verify that the task is being done as intended and, if not, correct the problem (Cascio 1996; Wilson 1998; Woodside et al. 1998). Thomas (2005 p. 188) comments:

> "*Environmental management systems are the most significant innovation to hit the corporate world since pollution control regulations were introduced in the mid-20th century. They have facilitated an era of environmental consciousness that has the potential to develop a strong environmental understanding across private industry and government.*"

Unlike the "command-and-control" policy instrument, which imposes requirements on organizations from the outside, an EMS consists of a regulatory structure that arises within an organization. An EMS represents a collection of internal efforts at policymaking, planning, and implementation that yields benefit for the organization as well as potential benefits for society at large (Fiorino 1999; Orts 1995). The main standard for EMS is ISO 14001, which was released in 1996 and designed to enable an organisation to "formulate a policy and objectives taking into account legislative requirements and information about significant environmental impacts" (Standards Australia and Standards New Zealand 1995, p. 3).

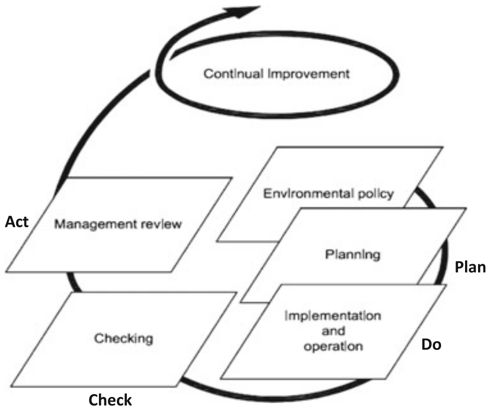


Fig. 5.2 The environmental management system model

As shown in Fig. 5.2, an EMS follows a Plan-Do-Check-Act, or PDCA cycle. The diagram shows the process of using the environmental requirements to develop an environmental policy, planning the EMS, and then implementing it. The process also includes checking the system and acting on it. The model is continuous because an EMS is a process of continual improvement in which an organization is constantly reviewing and revising the system. The EMS is based on the following philosophy:

- pollution prevention, conservation, and remediation;
- compliance with environmental regulations;
- environmental stewardship; and
- continual improvement.

The philosophy itemised above is achieved through the five stages, as shown in Fig. 5.2. The environmental management system model is well structured in the Standards Australia and Standards New Zealand (1995). It includes the following stages (see Fig. 5.2):

- general requirements;
- environmental policy;
- planning;
  - environmental aspects
  - legal and other requirements
  - objectives, targets and programs
- implementation and operation;
  - resources, roles, responsibility and authority
  - competence, training, and awareness
  - communication and documentation
  - control of documents
  - operational control
  - emergency preparedness, and response.

- checking and corrective action;
  - monitoring and measurement
  - evaluation of compliance
  - non-conformance, corrective/preventive action
  - control of records
  - internal audits
- management review;
- continual improvement.

Implementation of an environmental management system can provide several economic and non-economic benefits for organisations (Potoski and Prakash 2005). Organisations implementing EMS can have improvement in terms of environmental as well as overall performance that result in improved regulatory compliance, decreased waste materials, reduced pollution emission, enhanced corporate image, improved production efficiencies, increased customer satisfaction, access to new markets, and increased profits (Darnall et al. 2008; Potoski and Prakash 2005; Stapleton et al. 2001).

5.3.1.1 Environmental Management

Environmental management can be defined as the science of controlling and taking charge of our surroundings, especially the biological and physical elements of our lives, such as air, water, plants and animals (Thomas 2005). Environmental management can also be defined as a process that industries, companies, and individuals undertake to regulate and protect the health of the natural world. In most cases, it does not actually involve managing the environment itself, but rather is the process of taking steps and promoting behaviors that will have a positive impact on how environmental resources are used and protected. Organizations engage in environmental management for a couple of different reasons, but caring for the natural world, following local laws and rules about conservation, and saving money are usually near the top of most lists. Management plans look different in different industries, but all aim for roughly the same goals.

Most management plans roughly follow an ISO 9001: "plan, do, check, act" circle. The first step, planning, requires the organization to set out specific goals, like reducing wastewater, implementing new standards for toxin disposal, or better managing erosion (information on subsequent steps is provided in Sect. 3.2.2). Once an end-point has been identified, the manager then need to come up with a systematic way of bringing the entire organization into compliance.

5.3.1.2 Complying with Environmental Regulations

Compliance is a fairly straightforward concept of acting in accordance with established laws, regulations, protocols, standards and specifications. The critical issue centers around the cost of noncompliance, which can be civil, criminal, administrative, reputational, financial or market based. Environmental compliance typically includes compliance with environmental laws (enacted by legislative bodies), environmental regulations (created by regulatory bodies), standards, and other requirements such as site permits, licences, and approvals to operate. In recent years, environmental concerns have led to a significant increase in the number and scope of compliance imperatives across all global regulatory environments. Being closely related, environmental concerns and compliance activities are increasingly being integrated and aligned to some extent in order to avoid conflicts, wasteful overlaps and gaps (Tarantino 2008).

Having a sound environmental compliance program is increasingly vital to the success of any organization. Many of them, however, are unsure how to proceed with an effective plan of action. This uncertainty is magnified by the myriad federal, state, regional, and local government environmental laws and regulations. Almost all environmental laws use eight compliance obligations or regulatory approaches. Typical approaches include:

1. process controls and pollution prevention;
2. polluter-pays;
3. precaution;
4. transparency and public participation;
5. subsidiary;
6. discharge and waste control;
7. product controls; and
8. response and remediation requirements.

To achieve compliance with environmental requirements, a number of targeted measures are applied by both the Australian and State/Territory environmental departments (e.g., Department of Sustainability, Environment, Water, Population and Communities (DSEWPC). This department is charged with the responsibility of monitoring compliance with the regulations, detect, and react to contraventions. Compliance monitoring takes place through the following channels:

1. regular and random patrols;
2. audits;
3. regular and random inspections;
4. targeted investigations; and
5. analysis of information reported as a condition of licenses, approvals and other authorizations.

At the same time, the authorities apply a range of compliance encouragement measures, such as targeted communication and education activities; timely provision of information and advice; persuasion, collaboration, and cooperative assistance.

Where the compliance approaches fail, enforcement mechanisms are used. The department employs a range of enforcement sanctions to ensure the most appropriate response to breaches of its legislation or program requirements. Sanctions may include exclusion from programs, suspension or cancellation of permits, injunctions, remediation orders, pecuniary penalties (fines), and criminal prosecution.

The 2004 Australian Government Department of Environment and Heritage (DEH), Compliance and Enforcement Department of Environment and Heritage (CEDEH), Compliance and Enforcement Policy (CEP) documents set out the policy framework and instruments used when dealing with contravention of legislation. These include:

- court injunctions;
- stringent civil and criminal penalties;
- obligatory environmental audits;
- remediation of environmental damage;
- publicizing contraventions; and
- liability of executive officers.

Self-regulation: A Proactive Approach to Complying with Environmental Regulation

In order to demonstrate their environmental stewardship and discourage "command and control" environmental policy instrument, many proactive industries have initiated environmental programs that go beyond regulatory compliance. They have established their own standards of behavior that assist in complying with or exceeding pre-existing statutory and/or regulatory requirements. This voluntary initiative is called self-regulation, which is sometimes known as *environmental voluntarism* (see e.g., Gunningham 2007). Self-regulation is primarily based on compliance with regulations or a set of standards that addresses a perceived gap in regulation. It enables industry to propose alternative ways of complying with regulations by using different means to achieve environmental goals. Self-regulation programs can also be industry codes of conduct that are sponsored by trade associations designed to improve members' environmental performance. Best known examples of environmental self-regulation include the chemical industry's Responsible Care Program, which applies in over 40 countries, safety regulation of nuclear power plants by the Association of Nuclear Power Producers (INDO) in the United States and the Canadian forest industry's Sustainable Forest Management Certification (Gunningham 2007). Other self-regulatory approach is the Australian Manufacturers Council's Best Practice Environmental Management.

Since the 1990s there are many examples of how business organisations use environmental policies to demonstrate their self-regulatory approach to environmental compliance. The policies for Woodside Petroleum and Rio Tinto group, illustrated in Figs. 5.3 and 5.4, indicate some of the variety in policy style; many other businesses now have policies that can be obtained direct from their websites. The main point of adopting a policy is to provide direction for future actions within the organisation.

There are good reasons why an organisation should embrace self-regulatory approach to environmental compliance. Gunningham (1994) suggests that first, there is continual pressure from government command and control regulations; he warns that the environmental regulation is inevitably getting tighter. Second, there is increasing pressure from the public (consumer pressure, community pressure, investor pressure, etc.). Third, there are significant opportunities for competitive advantage and increased profitability in adopting a proactive environmental strategy; he sees this as moving from risk to opportunity.

environment policy

objectives

Woodside recognises that strong environmental performance is essential to our success and our continued growth. We are committed to managing our activities to reduce the adverse effects on the environment while balancing economic and social needs of sustainable development.

Woodside will set internal targets that challenge Woodside to improve our environmental performance over time. We will also report our environmental performance openly and transparently.

principles

Woodside will achieve these objectives by:

- Being constantly aware of our major environmental risks and ensuring the right designs, plans, actions and competent people are in place to control them.
- Using energy, water and other resources efficiently and reducing greenhouse gas emissions and waste.
- Integrating environmental requirements when designing or modifying facilities in order to reduce life cycle costs and environmental impacts.
- Complying with relevant laws and regulations and applying responsible standards where laws do not exist.
- Reducing the environmental impact of our activities.
- Supporting research to improve our understanding of the environment and using science to support impact assessments and decision making.
- Taking a collaborative approach with our stakeholders.

application

Responsibility for the application of this policy rests with all Woodside employees, contractors and joint venturers engaged in activities under Woodside operational control. Woodside managers are also responsible for promotion of this policy in non-operated joint ventures.

December 2013

woodside

Fig. 5.3 Example of corporate environmental policy—Woodside Petroleum

RioTinto

Environment policy

Wherever possible we prevent, or otherwise minimise, mitigate and remediate, harmful effects of the Group's operations on the environment.

Excellence in environmental performance is essential to our business success. Compliance with all environmental laws and regulations is the foundation on which we build our environmental performance. We support and encourage further action by helping to develop and implement internationally recognised management systems and voluntary commitments.

We similarly approach a comprehensive understanding of the full life cycle and safe use of our products to ensure all their benefits are delivered.

We promote active partnerships at international, national, regional, and local levels. They are based on mutual commitment, trust, and openness. Our relationships with communities involve consultation to open new facilities, to run existing ones and to close them at the end of their productive lives. In doing so, we support community based projects that can make a difference in a sustainable way without creating dependency. We also assist regional development and training, employment and small business opportunities. In developing countries, we are often asked to support health, education, and agricultural programmes and, in collaboration with others, we help where practical.

Fig. 5.4 Example of corporate environmental policy—Rio Tinto

5.3.2 *The PMBoK Guide*

The guide to the project management body of knowledge (PMBoK) is an inclusive term that describes the sum of knowledge within the profession of project management. As with other professions such as law, engineering, accounting, medicine and computing, the body of knowledge rests with the practitioners and academics who apply and advance it. The full PMBoK includes knowledge of proven, traditional practices, which are successfully applied throughout the world, as well as innovative and advanced techniques, which have had limited use and exposure (PMI 1996).

The PMBoK Guide is process-based, meaning it describes work as being accomplished by processes, and the ten knowledge areas embedded in the PMBoK Guide, are generally accepted as best practices within the project management discipline. PMBoK Guide provides the fundamentals of project management, irrespective of the type of project, be it construction, engineering, research and development (R&D), or development of a new product. The guide can also be a useful tool for developing an environmental project management framework.

The guide recognizes 47 processes that fall into five basic process groups and ten knowledge areas that are typical of most projects, most of the time. Each of the ten knowledge areas contains the processes that need to be accomplished within its discipline in order to achieve effective project management. Each of these processes also falls into one of the five process groups, creating a matrix structure such that every process can be related to one knowledge area and one process group. Detailed information is provided in Chap. 4.

In project management circles, it's joked that "there's the right way, the wrong way, and the PMBoK way" to manage projects. In truth, it's really about the methodology you choose. The PMBoK Guide is a consensus-based standard that thousands of project management professionals around the world find immensely valuable in the process of developing an effective methodology (Saladis and Kerzner 2011).

5.3.3 *ISO 9001 Plan Do Check Act (PDCA) Circle*

An underlying concept for the interaction among the project management processes is the "Plan-Do-Check-Act" circle advocated by Edwards Deming in the ASQ Handbook. It is sometimes called the Shewhart circle because it was originally adopted from Walter Shewhart (Russell 2005). The circle is linked by results; the result from one part of the cycle becomes the input to another. Thus, the circle fits completely with project management principles. To fulfill the goal of any project, first you plan what you're going to do, then you do it. Next, you check on what you did. You fix what didn't work. Then you execute what you set out to do. The circle works as a continuous improvement system. When the project is complete, you examined the lesson learned in its planning and execution phase. You incorporate those lessons into the project management processes and begin "Plan-Do-Check-Act" circle all over again on a new project (Kerzner 1984). To "Act" in "PDCA" sense means to reflect upon lessons learned and provide feedback for corrective actions to do the next iteration of the plan.

The four phases in the "Plan-Do-Check-Act" circle involve the following activities:

1. **Plan**: identifying and analyzing the problem.
2. **Do**: developing, organising, and testing a potential solution.
3. **Check**: leading the project team, measuring how effective the test solution was; and analyzing whether it could be improved in any way.
4. **Act**: implementing the improved solution fully.

Figure 5.5 illustrates the principles of project management, incorporating the input-output process, the "Plan-Do-Check-Act" circle and the appropriate project management knowledge areas throughout the project life cycle.

5.3.4 *The Six Sigma (DMAIC) Systems*

Define, measure, analyze, improve and control (DMAIC) is a structured problem-solving methodology, which is used as a means of approaching an issue in a structured way thus enabling solutions to be more robust and sustainable. It is an integral part

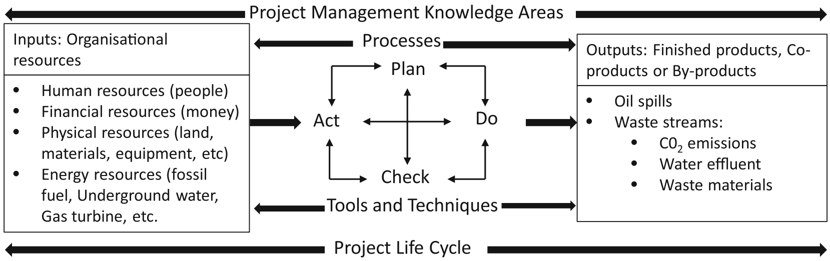


Fig. 5.5 Plan-Do-Check-Act methodology, incorporating the input-output processes, project management knowledge areas, tools and techniques

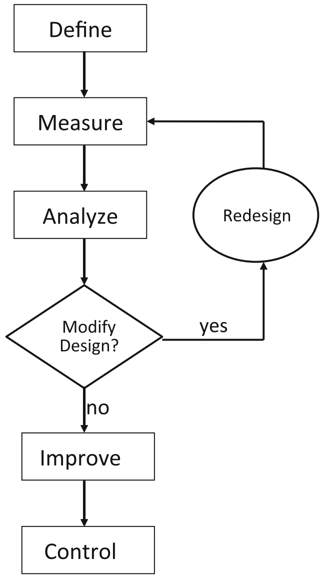
of a Six Sigma initiative, but in general can be implemented as a stand alone quality improvement procedure or as part of other process improvement initiatives such as environmental management systems (EMS) or PDCA circle. Each phase builds on the previous one, with the goal of implementing long-term solutions to problems. Sometimes, project leaders or sponsors don't feel a formal approach is necessary, but most problem-solving efforts benefit from a disciplined method.

Contrary to the PDCA approach discussed in the earlier section, the DMAIC approach offers an incremental performance improvement. It is based on a rigorous methodology that is adapted to complex problems whose solution is unknown. It proposes to increase performance through a structured and systemic way.

The five steps of the DMAIC, which is shown as a flow chart in Fig. 5.6 contain the following phases:

1. **Define** the environmental problem: the project goals, and customer (internal and external) requirements.
   The tools used in the define phase lay the foundation for the project. The team accurately and succinctly defines the problem, identifies customers and their requirements, and determines skills and areas that need representation on the project team. Individuals who must be part of the core team or be ad-hoc members are identified, and project measures, financials, and a communication plan are established.
2. **Measure** process performance.
   The measure phase is when the true process is identified and documented. Process steps, and corresponding inputs and outputs are identified. Measurement systems are identified or developed, and validated and improved as required. Baseline performance is established with trustworthy data.
3. **Analyze** the process to determine root causes of variation, poor performance (defects).
   In the analyze phase, the critical inputs are identified. Inputs that have a strong relationship with the outputs and root causes are determined. These critical inputs are the drivers of performance.

Fig. 5.6 Flowchart of the phases of DMAIC system



4. **Improve** process performance by addressing and eliminating the root causes.
   In the improve phase, potential solutions are identified and evaluated, and the process is optimized. The critical inputs that must be controlled to maintain performance that reliably satisfies the customer are determined. Process capability and project financials are estimated.
5. **Control** the improved process and future process performance.
   The control phase establishes mistake-proof, long-term measurement and reaction plans. The team develops standard operating procedures and establishes process capability. Project financials are updated, verified and reported. Control plans are established with reaction plans, ownership and control is transitioned to the process owner, and lessons are documented. The team documents opportunities to spread the outcomes to other areas in the organization.

5.4 Concluding Remarks

This chapter proposes a broad framework for managing environmental-based projects. The framework is based on the universal principles of the PMBoK guide, PDCA and six sigma DMAIC methodology, in conjunction with existing environmental policy, regulations and compliance strategy. The framework is also based on the generic process flows of initiating, planning, executing, controlling, monitoring and closing (IPECC), using environmental project management methods such as EIA, stakeholder analysis, network diagramming, GIS and photogrammetry. The EnvPM framework developed should be reviewed frequently to assess its efficiency in generating the right project objectives and effectiveness in delivering them successfully.

References

Cascio J (1996) Background and development of ISO 14000 series. In: Cascio J (ed) The ISO 14000 handbook, information services, Fairfax, VA, pp 4–23

Clark D (1999) What drives companies to seek ISO 14000 certification? Pollution Engineering, Summer 14–18

Darnall N, Henriques I, Sadorsky P (2008) Do environmental management systems improve business performance in an international setting? J Int Manag 14(4):364–376

Fiorino DJ (1999) Rethinking environmental regulation: perspectives on law and governance. Havard Environ Law Rev 23(2):441–469

Graff S (1997) ISO 14000: should your company develop an environmental management system? Ind Manag 39(6):1922

Gunningham N (1994) Beyond compliance: management of environmental risk. In: Boer B, Fowler R, Gunningham N (eds) Environmental outlook: law and policy. Federation Press, Sydney, pp 254–281

Gunningham N (2007) Reconfiguring environmental regulation: next generation policy instruments. In: Parto S, Herbert-Copley B (eds) The book industrial innovation and environmental regulation: developing workable solutions. International Development Research Centre, United Nations University Press, New York, 305p

Hoffman A (1994) Organizational change and the greening process at amoco. Total Qual Environ Manag 4(1):1–21

ISO (2001) The ISO Survey of ISO 9000 and ISO 14000 Certificates (Eleventh Cycle 2001). International Organization for Standardization, Geneva, Switzerland. http://www.iso.ch/iso/en/prods-services/otherpubs/pdf/survey11thcycle.pdf. Accessed 15 Feb 2014

Kerzner H (1984) Project management: a systems approach to planning, scheduling, and controlling, 3rd edn. Van Nostrand Reinhold, New York

Litskas M (1999) US perspective varies on ISO 14000. Quality 36(12):2833

Orts EW (1995) A reflexive model of environmental regulation, business ethics quarterly. Environ 5(4):779–794

PMI (1996) A guide to the project management body of knowledge (PMBOK guide). Newtown square. Project Management Institute, PA

Potoski M, Prakash A (2005) Green clubs and voluntary governance: ISO 14001 and firms' regulatory compliance. Am J Polit Sci 49(2):235–248

Russell JP (2005) The ASQ auditing handbook: principle, implementation and use. ASQ Quality Press, Milwaukee, 351p

Saladis FP, Kerzner HR (2011) Bringing the PMBOK guide to life: a companion for the practicing project manager, technology and engineering. Wiley, Hoboken, 288p

Standards Australia and Standards New Zealand (1995) Environmental management systems—specification with guidance for use: AS-NZS ISO 14001. SAA, Sydney

Stapleton P, Glover M, Davis S (2001) Environmental management systems: an implementation guide for small and medium sized organizations, 2nd edn. NSF International, Ann Arbor

Tarantino A (2008) Governance, risk, and compliance handbook: technology, finance, environmental, and international guidance and best practices. Wiley, Hoboken, 784p

Thomas IG (2005) Environmental management processes and practices for Australia. The Federation Press, Annandale, 360p

Thomas IG (2007) Environmental policy: Australian practice in the context of theory. The Federation Press, Annandale, 492p

Vastag G, Rondinelli DA, Kerekes S (1996a) How corporate executives perceive environmental issues: comparing Hungarian and global companies. J Euromarketing 5(3):527

Vastag G, Rondinelli DA, Kerekes S (1996b) Evaluation of corporate environmental management approaches: a framework and application. Int J Prod Econ 13(23):193–211

Watson M, Emery RTA (2004) Environmental management and auditing systems: the reality of environmental self-regulation. Manag Audit J 19(7):916–928

Wilson C (1998) Preventing and mitigating environmental enforcement with an EMS. Pollut Prev Rev 8(3):29–37

Woodside G, Aurrichio P, Yturri J (1998) ISO 14001 implementation manual. McGraw-Hill, New York

Yosie T, Herbst T (1996) Corporate environmental, health and safety practices in transition: management system responses to changing public expectations, regulatory requirements and incentives, global environmental management initiative, Washington DC. BIJ 10(2):106

Chapter 6
Environmental Project Economics

No longer is economics merely a science of production and distribution; it has to take into account the ecological repercussions of economic activities that could affect both production and distribution.

—Arun Balasubramaniam

6.1 Introduction

In this chapter, we strive to explain the application of microeconomic theory to environmental problems; limitations of market and government coordination of natural resource use, the relationship between the economy and the environment, and most especially, the cost-benefit analysis of green house gas effect, environmental pollution, and global warming.

As indicated in previous chapters, whilst there are numerous considerations and factors to be taken into account in environmental project evaluation, costing and selection, it is essential that any project undertaken should have a high probability of being financially viable, environmentally sound, and socially acceptable. No course on environmental project management would be complete without an introduction to the method used in evaluating and costing environmental projects.

Economic evaluation methods are tools and techniques used during the initiation phase of environmental project management to measure the project's benefit or value to the organization. They are used to compare the measurable benefits of one project against another. Selection methods are also used to evaluate and choose between alternative ways of performing the project.

Generally, organizations use different economic computer models with varying degrees of sophistication to evaluate their environmental projects. This depends on the application required. Simple tools, such as Excel spreadsheets may be used for early screening and ranking evaluations. Full economic evaluations for budget proposals require more comprehensive models, which fully reflect the fiscal and contractual terms applicable to the project and allow a more elaborate environmental risk assessment and sensitivity analysis to be made.

E.A. Sholarin and J.L. Awange, *Environmental Project Management*,
Environmental Science and Engineering, DOI 10.1007/978-3-319-27651-9_6

6.2 The Role of Economics in Environmental Project Management

As society moves through the twenty-first century, the resource sector faces an important challenge: to continue to develop economically without further damaging the environment. Thus, the purpose of this section is to understand the role of economics in solving problems of environmental pollution. Environmental management has two major objectives: to control the amount and level of pollution and to upgrade the environmental quality to an acceptable level. So far, attempts are made to achieve these objectives mainly through two different management strategies: *command-and-control* and *economic instruments*. The latter has proved to be more effective and created a win-win relationship between governments and the firms.

A case in point is the introduction of carbon tax in July, 2012 by the Commonwealth government of Australia as an economic instrument for implementing a carbon pricing policy. It's main aim was to reduce greenhouse gas emissions in Australia by 5 % below 2000 levels by 2020 and 80 % below 2000 levels by 2050. A report by a British risk analysis company showed Australia as one of the world's biggest carbon dioxide polluters (see e.g., Clarke 2009; Lauder 2009). Despite the devastating report, the current government of Australia abolished carbon tax policy in July, 2014 (see e.g., Taylor 2014; Tobin 2012). The main reason provided was to lower costs for Australian businesses and ease cost of living pressures on households! If that is the case, then the pertinent question to ask is: will the abolition of carbon tax have a direct positive impact on power bills for the households? If not, what then is the rationale for scrapping the carbon tax? These are the type of questions concerned member of the public would be asking.

One of the most pervasive applications of economic theory is that it logically explains the behaviour of consumers (households) and producers (firms) *vis-a-vis* the decision making process that takes place in the market place. This same application of economic theory can be used to analyze the relationship between society, industry, and nature. Environmental economics is concerned with identifying and solving the problem of environmental damage or pollution associated with the flow of residuals acquired from mass transport, manufacturing processes, telecommunications and synthetic chemicals (Callan and Thomas 2007). These residuals are responsible both for the highly advanced lifestyle that society enjoys, and for much of the environmental damage it now faces. Therefore, an important objective of environmental economics is to understand the critical relationship between economic activity and nature, and to use that knowledge to make better and wiser decisions.

As a society, we are still learning about nature, about market behavior, and about the important relationships that link the two together. What economics contributes to this learning process are analytical tools that help to explain the interaction of markets and the environment, the implications of that relationship, and the opportunities for effective solutions. Figure 6.7 clearly shows this relationship, and explained in more detail, using the circular flow model discussed in the next section.

6.3 The Circular Market Economy

Traditional market economy comprise of producers, consumers, and the market place (Asafu-Adjaye 2009). People are employed in the industry to produce goods and services in exchange for an income. The goods and services are then sold in the market place to the consumers for money (Smith 1776).

A typical circular flow model is shown in Fig. 6.1. Running anticlockwise is the resource (or non-monetary) flow between the consumers (society) and the producers (firms). Holding everything else constant, the society supplies natural resources or factors of production to the "factor" market, where they are demanded by the industry to produce raw materials or finished goods. These goods and the associated services are then supplied to the output market, where they are demanded by the society in order to satisfy its needs. Running clockwise is the money (or cash) flow. The exchange of inputs in the "factor" market generates an income flow to the society and that flow represents cost incurred by the industry.

Analogously, the money flow through the "output" market shows how society's expenditures on raw materials are revenues to the industry (Callan and Thomas 2007). Notice that the circular flow model as shown in Fig. 6.1 does not show the linkage between economic activity and its impact on the environment, which is the core area of environmental economics. Hence the need for an expanded model that depicts the flow of residuals from economic activities between the society and the industry. Figure 6.7 is used to illustrate this phenomenon. In the meantime, lets discuss the components of circular market economy, which are the resources derived from the society and raw materials used by the industry to produce finished goods.

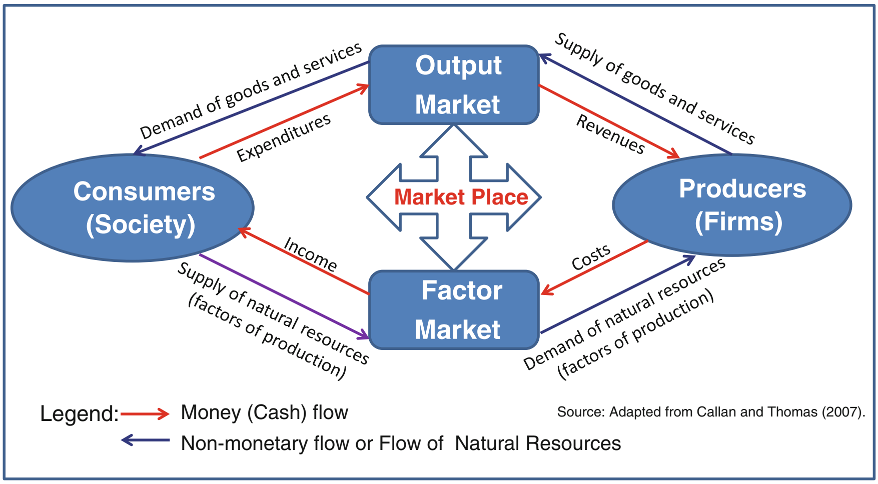


Fig. 6.1 An example of a circular market economy

6.3.1 Market Demand for Natural Resources

Demand is defined in economics as a *functional relationship* between the price of a good or service and the quantity demanded by consumers in a given period of time, *ceteris paribus*, i.e., holding everything else constant. A functional relationship means that demand focuses not just on the current price of the goods and the quantity demanded at that price, but also on the relationship between different prices and the quantities that would be demanded at those prices (Farnham 2010).

The quantity demanded of a product is a function of five factors;

- the price of goods demanded (energy or mineral resources),
- the price of other goods (air, water, land, autogas),
- consumer income (an increase in consumer income, *ceteris paribus*, will cause an increase in demand of a normal good and vise versa.),
- consumer tastes and preferences (people desire to ride bikes instead of driving cars), and
- number of consumers.

These are the only factors that influence demand. Anything else will work through one or more of the other mechanisms. For example we can write the demand function for an energy resource (e.g., crude oil) as follows:

$$QD_{oil} = f(P_{oil}, P_{Biofuels}, P_{LPG}, \text{ I, T, NC,...}), \tag{6.1}$$

where:

QD_{oil} = quantity demanded of crude oil, millions of barrels per day
P_{oil} = price of crude oil, \$ per barrel
$P_{Biofuels}$, P_{LPG} = price of goods related in consumption to crude oil (e.g. biofuels, LPG)
I = income
T = variables representing an individual's tastes and preferences
NC = number of consumers in the demand market.

Equation 6.1 is read as follows: the quantity demanded of crude oil is a function of the variables inside the parenthesis. An ellipsis is placed after the last variable to signify that many other variables may also influence the demand for crude oil. These may include variables under the control of the project manager, such as scheduling, budgeting, and variables not under anyone's control, such as the weather condition.

The functional relationship between the price of a good and quantity demanded by a consumer is portrayed graphically in Fig. 6.2.

A demand curve (Fig. 6.2) for product i shows for each price of good i (vertical axis), the quantity demanded of good i (horizontal axis), holding all other things equal, *ceteris paribus*.

Demand curves are generally downward sloping, showing a negative or inverse relationship between the price of a good and quantity demanded at that price, other

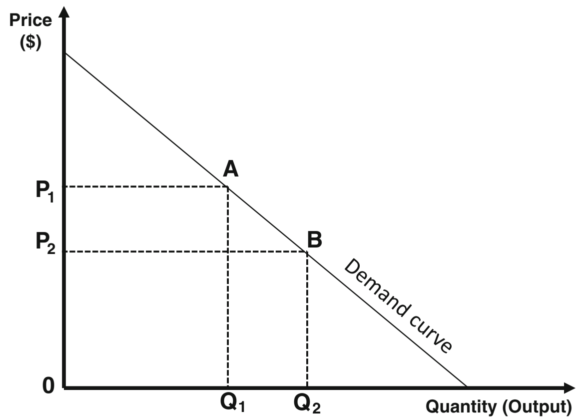


Fig. 6.2 A demand *curve* for a natural resource (e.g., crude oil)

factors remain equal. Thus, in Fig. 6.2, when the price falls from P_1 to P_2, the quantity demanded is expected to increase from Q_1 to Q_2, if nothing else changes. This is represented by the movement from point A to point B in Fig. 6.2. Likewise, an increase in the price of the good results in a decrease in quantity demanded, other factors remaining constant.

Why does the demand curve slope downwards? We shall try to explain this using the concept of opportunity cost. A demand curve shows the quantity that consumers wish to buy at each price level. As the price of a good increases, consumers have to use more of their limited resources to buy the good. The *opportunity cost* of buying a good is the units of pleasure derived from consuming other goods that a consumer would have purchased but can no longer afford. The higher the price of a good in question, the more of the other goods the consumer has to forego. Hence, opportunity cost increases as price rises.

As the price (and hence opportunity cost) increases, more and more consumers will decide that the opportunity cost outweighs the benefit derived from consuming the good in question. Therefore they choose not to purchase the good and so the quantity demanded decreases as price rises.

6.3.2 Market Supply for Natural Resources

We now examine producer decisions to supply various goods and services and the factors influencing those decisions. Supply is the functional relationship between the price of a good or service and the quantity that producers are willing and able to supply in a given time period, *ceteris paribus* (Farnham 2010).

The quantity supplied of a good is a function of four factors;

- the prices of the goods (e.g., energy, minerals and other natural resources),
- the *opportunity cost* of resources needed to produce the good (the prices of other resources that can be substituted),

- state of technology (technology available to produce the good, or the body of knowledge about how to combine factors of production), and
- number of producers in the supply market.

A supply function for a product, which is defined in a manner similar to a demand function, is shown in Eq. 6.2:

$$QS_{oil} = f(P_{oil}, T_x, P_i, P_A, P_B, \text{ I, T, NP,.....}) \tag{6.2}$$

where:

QS_{oil} = quantity supplied of crude oil, millions of barrels per day
P_{oil} = price of crude oil, $ per barrel
P_i = prices of inputs of production
T_x = state of technology
P_A, P_B = prices of goods A and B, e.g., liquified natural gas (LNG) and liquified petroleum gas (LPG), which are related in production to crude oil.
I = income
T = variables representing an individual's tastes and preferences
NP = number of producers in the supply market.

The supply curve in Fig. 6.3 shows the relationship between price (P) on the vertical axis and quantity supplied (Q) on the horizontal axis, holding all other variables constant. As can be seen in Fig. 6.3, a supply curve generally slopes upward, indicating a direct relationship between the price of the good and the quantity producers are willing to supply. A higher price typically gives producers an incentive to increase the quantity supplied of a particular good because higher production yields more revenue.

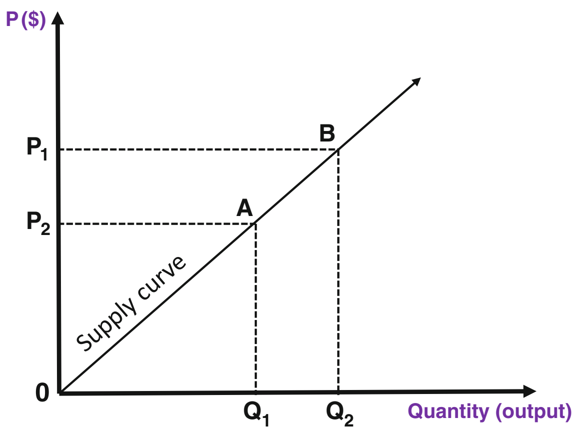


Fig. 6.3 A supply curve for natural resources (crude oil)

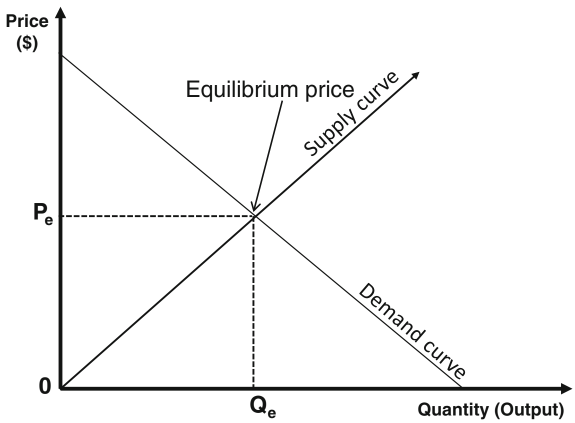
6.3.3 The Law of Supply and Demand

There is an economic theory explaining the interaction between the supply of a resource and the demand for that resource. This theory led to the formulation of a fundamental economic law, called the *law of supply and demand*. The law states that "the quantity of goods in a market place at a given time is directly proportional to the price of goods supplied, and inversely proportional to the price of goods demanded, *ceteris paribus*".

The law of supply and demand defines the effect that the availability of a particular product and the desire (or demand) for that product has on price. The law of demand applies when other factors that might affect demand, such as changes in income or taste are assumed to be constant. Similarly, the law of supply applies when other factors that might affect supply (e.g., state of technology, number of producers in a market place) are assumed to be constant. Generally, if there is a low supply and a high demand, the price will be high. In contrast, the greater the supply and the lower the demand, the lower the price will be. In a competitive market, the interaction of demand and supply determines the *equilibrium price*, that is, the price that will actually exist in the market or toward which the market is moving. Figure 6.4 shows the equilibrium price P_e for good X (e.g., crude oil). The equilibrium price is the price at which the quantity demanded of good X by consumers equals the quantity that producers are willing to supply. The quantity is called the *equilibrium quantity*, and the market, where the demand curve crosses the supply curve is called the *market equilibrium*. The market of supply and demand is said to be in equilibrium when the quantity that firms (producers) want to supply is equal to the quantity that households (consumers) want to buy, i.e.,

$$QD_i = QS_i. \tag{6.3}$$

Fig. 6.4 Market equilibrium



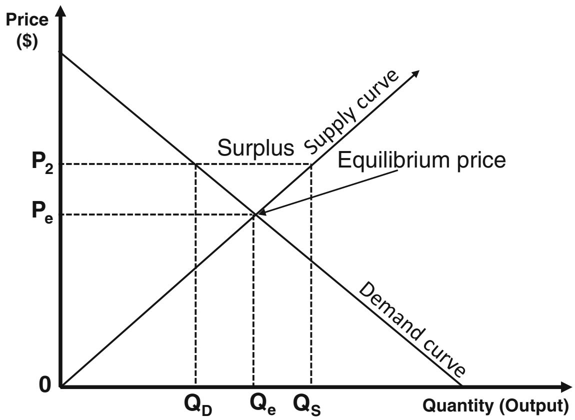


Fig. 6.5 Higher than equilibrium price

As can be seen in Fig. 6.4, there is a unique price at which this will occur for the following reasons:

1. if $QS_i > QD_i$, there will be a **surplus**. Figure 6.5 shows that P_2 is higher than the equilibrium price P_e. It can also be seen that the quantity demanded by consumers at price P_2 is lower than the quantity producers are willing to supply. This creates surplus of the good as shown in Fig. 6.5 and sets in motion forces that will cause the price to fall. As the price falls, the quantity demanded increases and the quantity supplied decreases until a balance between quantity demanded and quantity supplied is restored at the *equilibrium price*.
2. if $QS_i < QD_i$, there will be a **shortage**. Figure 6.6 shows the opposite case, a lower-than-equilibrium price. At price P_1, the quantity supplied QS_i is lower than the quantity demanded QD_i at that price. At price P_1, consumers demand more of the good than producers are willing to supply at that price. Because there is an imbalance between quantity demanded and quantity supplied at this price, the

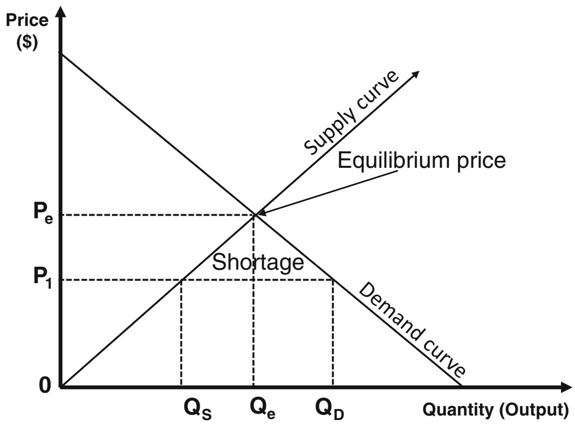


Fig. 6.6 Lower than equilibrium price

situation is not stable. Some individuals are willing to pay more than price P_1, so they will start to bid the price up. A higher price will cause the producers to supply a larger quantity. This adjustment process will continue until the equilibrium price has been reached and quantity demanded is equal to quantity supplied.

In the next section, we'll examine the inter-relationship between market economy and nature and the effect of residuals (industrial wastes, pollutants and greenhouse gas emissions) on the environment.

6.3.4 The Interdependence of Market Economy and the Environment

We now need to make Fig. 6.1 more meaningful since we did not specify formally what interactions take place within the economy (factor and output markets) and the environment. In Sect. 6.3, we began with the economic relationship between the output and factor markets. Now, we shall expand the picture to include the environment, and illustrate economy-environment interaction. The upper part of Fig. 6.7 shows the environment—the supplier of natural (renewable and nonrenewable) resources and 'sink' of wastes, (e.g., energy resources, fisheries, land, the capacity of the environment to assimilate waste products, and so on). The lower part shows the market economy. This part is concerned with the way in which various component parts of the economy interact—how consumers' demand affect energy output, how the

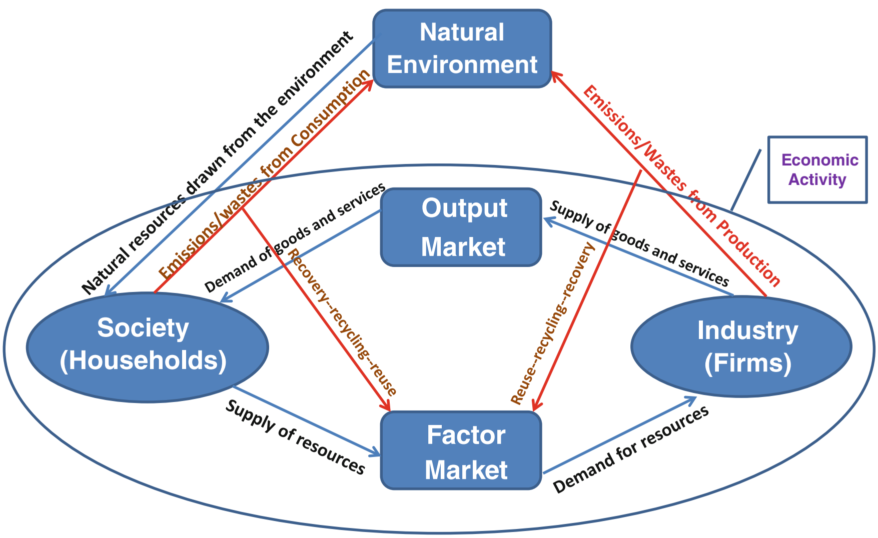


Fig. 6.7 Materials balance model: Interdependence of market economy and the environment

production of automobile gasoline and polypropylene affects the demand for crude oil and natural gas, how the overall size of the economy can be expanded and so on.

The explicit relationship between economic activity (market equilibrium) and the environment is illustrated by the material balance model shown in Fig. 6.7. Consumers (society) are, by assumption, the owners of all factors of production, including natural resources. The first set of linkages represents natural environment and the two (factor and output) markets. This flows describes how economic activity draws on the Earth's stock of natural resources, such as oil, coal, natural gas, minerals, water and soil to satisfy societal needs.

The second set of linkages runs in the opposite direction, from the market economy to the environment. This flow illustrates how raw materials entering the system eventually are released back into the environment as by-products or residuals. Most residuals are in the form of greenhouse emissions released into the atmosphere, causing environmental pollution and climate change. It is possible to delay, though not prevent, the flow of residuals back to the environment through replacement, recovery, recycling, reuse, and reduction, which is often referred to as the 5R *cleaner production strategy* (see e.g., Erkman and Ramaswamy 2001). The goal of environmental economics is to reduce the residuals to an acceptable level.

Notice in the model that there are inner flows running from the two residual outflows back to the economy. The inner flows show that some residuals can be recovered from the stream and either recycled into another usable form or reused in their existing form. Whatever is the case, we must recognise the first law of thermodynamics, which states that "matter and energy can neither be created nor destroyed". This means that every resource drawn into economic activity ends up as a residual, which has the potential to damage the environment. The process can be delayed through recovery or reuse, but not stopped.

Sequel to that is the second law of thermodynamics, which states that "nature's capacity to convert matter and energy is not without bound". This means that nature's ability to convert resources to other forms of matter and energy is limited. Consequently, the fundamental process on which economic activity depends is not finite. Figure 6.7 clearly shows that all resources drawn from the environment ultimately are returned there in form of residuals (Callan and Thomas 2007). Consequently, the market flow and the nature flow need to be balanced in order to optimise the effect of economic activity on the environment.

6.3.5 The Law of Diminishing Returns

Law of diminishing returns is one of the best-known principles outside the field of economics. It was first developed in 1767 by the French economist Turgot in relation to agricultural production, but it is most often associated with Thomas Malthus and David Ricardo (see e.g., Edward 2006). They believed human population would eventually outpace food production since land is an integral factor in that it exists in limited supply. In order to increase production to feed the population, farmers would

Table 6.1 Economic conditions of a farm producing wheat as biofuels

Number of workers	Wheat produced	Marginal benefit
1	10	10
2	25	15
3	45	20
4	60	15
5	70	10
6	60	−10

have to use less fertile land and/or increase production intensity on land currently under production. In both cases, there would be diminishing returns.

Law of diminishing returns, which is related to the concept of *marginal return* or *marginal benefit* states that if one factor of production is increased while the others remain constant, the marginal benefits will decline and, after a certain point, overall production will also decline. While initially there may be an increase in production as more of the variable factor is used, eventually it will suffer diminishing returns as more and more of the variable factor is applied to the same level of fixed factors, increasing the costs in order to get the same output. Diminishing returns reflect the point in which the marginal benefit begins to decline for a given production process. For example, Table 6.1 sets the some conditions on a farm producing wheat as biofuels:

From Table 6.1, it can be seen that it is with three workers that the farm production is most efficient because the marginal benefit is at its highest. Beyond this point, the farm begins to experience diminishing returns and, at the level of 6 workers, the farm actually begins to see decreasing returns as production levels decline, even though costs continue to increase. In this example, the number of workers changed, while the land used, seeds planted, water consumed, and all other inputs remained the same. If more than one input were to change, the production results would vary and the law of diminishing returns may not apply if all inputs could be increased. If this were to lead to increased production at lower average costs, economies of scale would be realized.

The concept of diminishing returns is as important for industries and society as it is for businesses because it can have far-reaching effects on a wide variety of things, including the environment. This principle, although first thought to apply only to agriculture, is now widely accepted as an economic law that underlies all productive endeavors, including resource use and exploration.

6.4 Economics of Environmental Pollution

Environmental economics is concerned with identifying and solving the problem of environmental degradation, or *pollution*, associated with the flow of residuals. Carllan and Thomas (2007) defined pollution as presence of matter or energy whose nature, location, or quantity has undesired effects on the environment. The economic definition of pollution is dependent upon both some physical effect of waste on the environment and a human reaction to that physical effect. The physical effect can be biological (e.g., species change, ill-health), chemical (e.g., the effect of acid rain on building surfaces), or auditory (noise).

In order to understand the physical effect of environmental pollution, the following illustration will suffice. Consider a market that produces crude oil (energy resource) and the associated physical/chemical effects (air pollution). The greenhouse gas emission is a byproduct of crude oil processing activities, which is directly proportional to the increase in volume of hydrocarbon production. Consumers value energy resources, such as petroleum, coal, and natural gas, but are harmed by the pollution—a thick, noxious smoke that damages health, destroys plants, soils clothing and houses. For simplicity, we assume that the only way to reduce environmental pollution is to reduce crude oil production. Smokestack scrubbers and other pollution control devices are assumed to be prohibitively expensive. Relaxing this assumption would complicate the analysis without changing the basic point.

Because competitive firms do not have to pay the costs associated with the pollution, (especially now that carbon tax is repealed in Australia) they underestimate the true costs of production and charge too little for their product, resulting in large revenue and too much pollution, as illustrated in Fig. 6.8. The demand curve, D, in Fig. 6.8 shows how much consumers (or households) are willing to pay for the supply of goods and services. Each firm has a private marginal cost curve (MC_s), which includes only the costs of producing goods and services, e.g., crude oil (capex, opex and drilling costs), and does not include the full social costs of the pollution. In Fig. 6.8, the market production curve (MC_p) is the horizontal sum of the private marginal cost curves of all the drilling rigs and production platforms in the market. That is, the (MC_p) curve ignores the harm done by the air pollution.

If the market is competitive, (MC_s) is the market supply curve. In the absence of government intervention, a competitive market ignores the pollution damage and

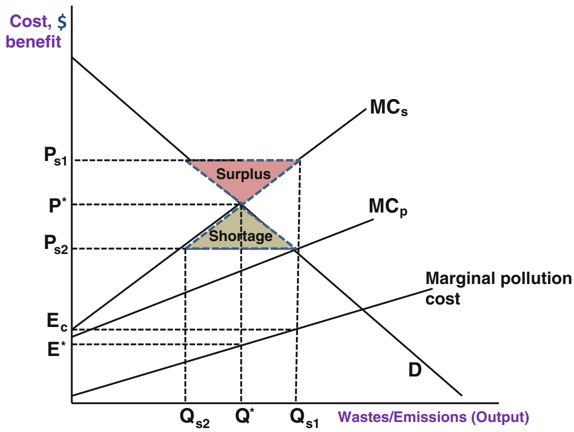


Fig. 6.8 The effect of carbon tax on industry price and output

produces where market supply curve, (MC_s), equals market demand curve, D. As Fig. 6.8 shows, the market provides (Q_{s1}) crude oil at a price of (P_{s1}).

Firms ignore the damage done by the air pollution they create. The dollar value of the marginal damage (health harms, property damage, reduced agricultural output, and so forth) is called the marginal pollution cost curve as shown in Fig. 6.8. The height of this curve shows how much compensation pollution victims would have to receive to be indifferent between tolerating incremental pollution and being compensated and not having to face the pollution caused by the last unit of production. In the competitive equilibrium where price is (P_{s1}) and quantity supplied is (Q_{s1}), the *marginal pollution cost* is (E_c).

The full cost of crude oil to the society, the social marginal cost, is the cost of producing hydrocarbon (the height on the (MC_p) curve) plus the marginal damage due to pollution. Thus the full marginal cost to society, (MC_s), is the vertical sum of the (MC_p) and the marginal pollution cost curve.

The producers' (or firms') Surplus (P_{sp}) is equal to the area of the upper triangle, which can be expressed in the following equation:

$$P_{sp} = \frac{Q^*(P_{s1} - P^*)}{2}. \tag{6.4}$$

The Producers' (or firms') shortage (P_{st}) equals to the area of the lower triangle:

$$P_{st} = \frac{Q^*(P^* - P_{s2})}{2}. \tag{6.5}$$

The only way to eliminate pollution completely is to shut down the hydrocarbon producing industry. Because consumers value crude oil (as shown by their demand curve), shutting down the industry would cause more harm than good. The socially optimal solution is to restrict output to Q^*, where the marginal social benefit, (value of the last barrel of crude oil) equals the social marginal cost (the marginal revenue and pollution costs). That is, the optimal solution is to produce at the price P* and quantity Q* where the (MC_s) and demand curve, D, intersect. At the optimum, the marginal cost of the pollution is E*, which is less than (E_c), but still positive.

6.5 Economic Evaluation of Environmental Projects

The purpose of an economic evaluation is to determine whether a project or investment is financially desirable. An economic evaluation determines if a particular project is worthwhile doing or not. Also, where there are list of projects, economic evaluation helps to compare, rank and select the best. In general, economic evaluations are conducted to justify the "quantitative" benefits of industrial projects, value an asset or equipment for sale, make acquisition, or obtain loans.

Economic evaluation of environmental projects has been pursued in many forms since the mid-1970s. It is usually undertaken in the form of benefit-cost analysis

(BCA) and cost-effectiveness, which are major techniques of economic decision-making. Application of BCA for evaluating environmental projects is outlined by Hundloe et al. (1990), who considers that BCA can be used in the analysis of need for a proposal, and for providing a way of comparing alternatives. Boer and James (1990) argued that monetary values can be placed on conventional goods and on environmental effects of projects, and outlined some techniques that can be used for this purpose.

In general, evaluation of projects in the environmental sector involve a variety of techniques, including cost-benefit analysis, payback period, discounted cash flow, net present value, return on investment or profit-to-investment ratio, internal rate of return and present worth ratio (PWR). We look at each of these techniques individually and provide a crash course on their meanings as well as calculations.

6.5.1 Cost Benefit Analysis

Cost-Benefit analysis is an investment analytic technique that can be applied to any systematic, quantitative appraisal of a public or private environmental project to determine whether or to what extent, that project is worthwhile from a public or social perspective (Hanley and Spash 1993). It compares the monetary value of benefits (e.g. the benefit of quicker and easier travel to work, reduced human and wildlife mortality, improved water quality, species preservation, and better recreation opportunities) with the monetary value of costs (e.g. the cost of environmental pollution, oil spill, greenhouse gas emission, industrial waste, etc.) of a proposed policy action in order to evaluate and prioritize environmental issues. The latter are market effects readily measured in dollars, while the former are non-market effects for which dollar values are not available. The final decision is informed (though not necessarily determined) by a comparison of the total costs and benefits. Cost-benefit Analysis is a quick and simple technique that can be used for non-critical financial decisions, where decisions are mission-critical or large sums of money are involved.

However, cost-benefit analysis of environmental project differs from other analytical approaches in the following respect: it demands that the advantages and disadvantages of a regulatory policy be reduced, as far as possible, to numbers, and then further reduced to dollars and cents (Ackerman and Heinzerling 2002). In this feature lies the main challenge of cost-benefit analysis. Estimating cost of pollution control equipment or carbon sequestration technology is easy and straightforward. But how does one monetise the benefit of a healthy environment?

It is important to note that there is a misconception that a project with the highest benefit-cost ratio should be selected when, in fact, the project that yields the highest net benefits to society is most desirable. In the example demonstrated in Table 6.2, the benefit-cost ratio is maximized with alternative C but welfare is maximized with alternative E. The selection of the plan with the highest benefit-cost ratio (Plan C) would result in $7 million in forgone net benefits, which would have been realized if Plan E had been selected ($182 million in net benefits for Plan E against $175

Table 6.2 Benefit-cost ratios and net benefits for illustrative CCS project

Plan	Benefits ($ million)					Costs ($ million)				Net benefits ($ million)	Benefit-cost ratio
	Tourism	Fishing	Seafood	Recreation	Total	Abatement	Fishing	Lost production	Total		
A	$ 400.00	$ 300.00	$ 100.00	$ 400.00	$ 1,200.00	$ 400.00	$ 300.00	$ 400.00	$1,100.00	$ 100.00	1.091
B	$ 350.00	$ 250.00	$ 300.00	$ 450.00	$ 1,350.00	$ 300.00	$ 500.00	$ 400.00	$1,200.00	$ 150.00	1.125
C	$ 450.00	$ 300.00	$ 350.00	$ 375.00	$ 1,475.00	$ 400.00	$ 350.00	$ 550.00	$1,300.00	$ 175.00	**1.135**
D	$ 500.00	$ 300.00	$ 250.00	$ 530.00	$ 1,580.00	$ 500.00	$ 400.00	$ 500.00	$1,400.00	$ 180.00	1.129
E	$ 400.00	$ 300.00	$ 500.00	$ 482.00	$ 1,682.00	$ 500.00	$ 500.00	$ 500.00	$1,500.00	**$ 182.00**	1.121
F	$ 350.00	$ 450.00	$ 550.00	$ 428.00	$ 1,778.00	$ 550.00	$ 450.00	$ 600.00	$1,600.00	$ 178.00	1.111

million for Plan C). Consequently, when selecting between two or more projects, the one with the highest net benefits should be considered.

How do we compare the costs of greenhouse gas mitigation measures taken today with the benefits produced by these actions in the future? How do we calculate the value of an investment when benefits will continue to accrue over centuries? These are important questions, because the way we value the benefits of mitigation measures will guide us in developing cost-effective solutions to the threat of climate change.

6.5.2 Cash Flow Analysis

This section presents the basic techniques for analyzing cash flow amounts located at discrete points in time. The projected net cash flow for a project is the aggregation of numerous component cash flows each of which has to be estimated and will, of course, be subject to forecasting errors.

Funds flow in and out throughout the life cycle of a project. It is important to evaluate the implications of cash flows and capital investments for environmental project management purposes. Cash flow analysis is usually carried out for investment decision making. At one extreme, the analysis may be very simple, e.g., estimating the future cost and timing of waste treatment in a contaminated site. At the other extreme, the analysis can be very complicated and may involve estimating the cash flows of a carbon dioxide sequestration program, which can take more than 15 years or more to accomplish with detailed fiscal calculations for each year.

Cash flow is simply the cash received (cash inflow) and the cash expended (cash outflow) over a defined period of time. Net cash flow is the difference between the two flows. This equation can be expressed mathematically as follows:

$$Net\ Cash\ Flow = Revenue - Expenses \tag{6.6}$$

The derivation of the future net cash flow of a project is essential in order to determine whether the project is economically viable. Figure 6.9 illustrates the net cash flow profile for a typical environmental project.

Environmental restoration or remediation projects will require millions of dollars to execute. Oftentimes, there will be more projects than there are funds available to execute. An economic analysis will be utilised in order to assist in the allocation of the available budget. The economic analysis provides a forecast of the future cash flow over time of each project opportunity expressed in dollar terms. However, in many situations, non-dollar considerations also enter the picture. Non-dollar considerations include company's environmental policy, safety, state/national/regional and international regulatory impacts, stakeholders, and community relations. These non-dollar considerations are also termed as *subjective factors*.

The economic analysis also derives measurement parameters from the cash flow forecasts. These measurement parameters include payout or payback period, present value, internal rate of return, profit-to-investment ratio and present worth ratio.

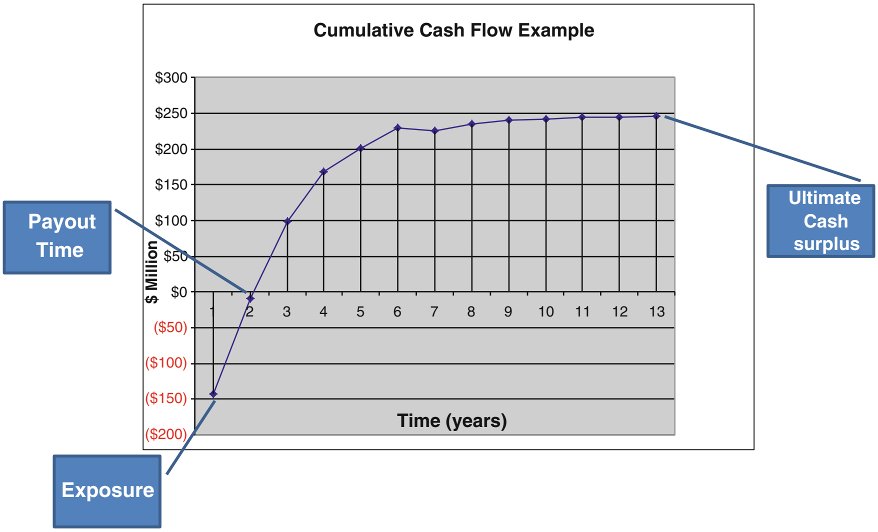


Fig. 6.9 Payback period chart, showing the cumulative cash inflow and cash outflow over a period of time

It is with these measurement parameters that the relative merit of each investment opportunity can be assessed so that the best opportunities can be pursued. These important indicators are called the *quantitative* or *objective* factors.

6.5.3 Payback Period

The payback, or pay-out is the length of time it takes a company to recoup its original investment. In order for an investment to provide value and profit, it must be able to generate enough cash flow to cover more than the dollars invested. Payback is a measure of how quickly the project cash flow will recover the initial cost of investment. In other words, payout occurs when the cumulative net cash recovery goes positive.

Other than providing information on the length of time required to recover the initial investment, payback does not provide any other information on how good an investment opportunity will be beyond this point in the life of the project.

To calculate the payback period, the project's net cash flow is added until the cumulative cash flow becomes positive. The length of time to achieve a total cumulative positive cash flow is the payback period (typically expressed in years). The calculations are shown in Table 6.3.

In this example, the payout can be seen to occur two years after the initiation of the project. This can be presented graphically as shown in Fig. 6.9. Payback period is the least precise of all the cash flow calculations. That is because payback does

Table 6.3 Net cash flow and payback period calculations

Year	#	Investment ($Million)	Revenue ($Million)	CAPEX ($Million)	Cash flow ($Million)	Cumulative cash flow ($Million)
		A	B	CAPEX	B − A	
	0				0	0
2015	1	$275.000	$132.900	$0.000	**($142.100)**	**($142.100)**
2016	2	$0.000	$132.900	$0.000	$132.900	**($9.200)**
2017	3	$0.000	$107.600	$0.000	$107.600	$98.400
2018	4	$0.000	$69.200	$0.000	$69.200	$167.600
2019	5	$0.000	$43.500	$10.000	$33.500	$201.100
2020	6	$0.000	$28.600	$0.000	$28.600	$229.700
2021	7	$0.000	$15.900	$20.000	**($4.100)**	$225.600
2022	8	$0.000	$9.400	$0.000	$9.400	$235.000
2023	9	$0.000	$5.600	$0.000	$5.600	$240.600
2024	10	$0.000	$1.900	$0.000	$1.900	$242.500
2025	11	$0.000	$1.500	$0.000	$1.500	$244.000
2026	12	$0.000	$1.200	$0.000	$1.200	$245.200
2027	13	$0.000	$1.000	$0.000	$1.000	$246.200
		$275.000	$551.200	$30.000	$246.200	$2,224.600

not consider the value of the cash inflows made in later years, that is, *time value of money*. For example, if you have a project with a five year payback period, the cash inflows in year 5 are worth less than they are if you received them today. This is because of time value of money, which will be well discussed in the next section.

6.5.4 Time Value of Money: Compounding the Future Cash Flow

"Compound interest is the eight wonder of the world. He who understands it, earns it...he who doesn't...pays it"—A. Einstein

Quantitative evaluation of environmental projects is based on "time value of money" concept discussed earlier. Let's assume that money available today can be invested in a reliable source, such as a bank or government security, and that the money must be able to produce some future gain with interest.

As stated earlier, money received in the future is worth less than money received today. The reason for that is the time value of money. If, for example, $2,000 is borrowed today from bank with a promise that it will be paid back in three years, it is normally expected to pay interest in addition to the original amount borrowed.

The bank has the option of putting same money in form of an investment that can generate additional return on the money. Therefore, the future value of the $2,000 you lent today is $2,315.25 in three years from now at 5 % interest per year, with the formula for future value (FV) given as;

$$FV_n = PV(1 + r)^n, \tag{6.7}$$

where $(1 + r)^n$ is called the *compound factor*.

From Eq. (6.7), the future value (FV) of the investment equals the present value (PV) times (1 plus the interest rate) raised to power (n), i.e., number of time period the interest is paid. Let's plug in the numbers:

$$\begin{aligned} FV_3 &= 2000(1.05)^3 \\ &= \$2315.25, \end{aligned} \tag{6.8}$$

thus if there is a guaranteed rate of return on investments of 5 % and there are no alternative forms of investments, then it makes no difference between receiving $2,000 today or $2,315.25 in three years' time.

6.5.5 Discounting the Future Cash Flow

When weighing the benefits and costs of an environmental project, the selection of a discount rate is a key consideration and often a source of controversy. What is a discount rate? The discount rate is the rate at which society as a whole is willing to trade off present for future benefits. When weighing the decision to undertake a project with long-term benefits (e.g., wetland protection programs) versus one with short-term benefits and long-term costs (e.g., logging forests near aquatic ecosystems), the discount rate plays an extremely important role in determining the outcome of the analysis. Indeed, a number of reasonable decision measures (e.g., net present value, internal rate of return, return on investment) depend critically on the chosen discount rate.

Why are discount rates needed? Because a dollar received today is considered more valuable than one received in the future. There are four primary reasons for applying a positive discount rate. First, positive rates of inflation diminish the purchasing power of dollars over time. Second, dollars invested today has the capability to earn a positive rate of return. Third, there is uncertainty surrounding the ability to obtain promised future income. That is, there is the risk that a future benefit (e.g., enhanced fish catches) will never be realized. Finally, humans are generally impatient and prefer instant gratification to waiting for long-term benefits.

This preference for instant gratification over gains and losses in the future is known as *discounting*. The rationale for discounting is based on *time value of money*, which can be examined from two dimensions;

- money to be received at some time in the future has less value than that same amount to be received sooner, and
- there is a preference to pay out money later rather than sooner because the money can be used for other beneficial purposes.

To understand the concept of "time value of money", consider a development that yields immediate and near-term benefits, but which has fairly catastrophic environmental consequences for future generations. Examples might be the emissions of chlorofluorocarbons (CFCs) that has the potential to damage the ozone layer, acid rain, greenhouse gas effect and so on. So long as the weight we attach to the future gets less and less, the further into the future we go, the less important such catastrophic losses will be. This is what discounting does to natural environment. In other words, discounting contains an in-built bias against future generations. Same argument can be used in support of exploitation of natural resources. the higher the discount rate—the rate at which the future is discounted—the faster the resources are likely to be depleted, which seems to be inconsistent with the concept of sustainable development, that is, the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED 1987). Consequently, time value of money for environmental projects must be applied only where the environmental benefits exceeds the associated costs, that is, when the present value of benefits is greater than the present value of costs.

6.5.6 The Rationale for Discounting

Inflation is the primary reason for discounting; however, independent of inflation, discounting is an important tool for assessing environmental benefit streams. Discount rates also reflect the *opportunity cost* of capital. The opportunity cost of capital is the expected financial return forgone by investing in a project rather than in comparable financial securities. For example, if \$100 is invested today in the private capital markets and earns an annual real rate of return of 10 %, the initial \$100 investment would be valued at \$254.94 at the end of 10 years. Therefore, discount rates reflect the forgone interest earning potential of the capital invested in an environmental project. The real opportunity cost of capital is often considered to be higher than the pure time preference rate. The former reflects the productivity of capital; the difference over time is not between the value of a dollar's worth of services consumed now and a dollar's worth of services consumed later, but rather a dollar's worth of services consumed now and the higher future consumption made possible by the return on investment.

Besides, environmental projects involve uncertainty and risk. When environmental projects are undertaken, including those that involve coastal or wetland restoration, there is a chance that future benefits will not be fully realized or realized at a higher level than estimated (there are also uncertainties associated with costs). For example, natural disaster could undermine efforts to restore wetland habitat, thus reducing or eliminating the future benefits that a restoration project would have generated. The further out into the future these benefits are expected to be realized, the greater the risk that some unexpected event or factor will occur and diminish the value of the future benefit.

6.5.7 Discounted Cash Flow

Discounted cash flow (DCF) is the computational technique that compares the value of the future cash flows of an environmental project to today's dollars. It can be used to discount the future benefits and costs of environmental projects. Discounted cash flow calculates the velocity of loss of value of money in the future. The larger the discount rate, the higher the velocity of loss of value. So, for example, a discount rate of 10 % to a benefit of $100 received in 10 years' time will be worth $38.55 now. If the discount rate is 3 %, the same amount of money received in 10 years' time will be worth $74.41 now. Mathematically, the present value of a future benefit or cost is computed based on the following equation:

$$PV_n = FV/(1+r)^n, \tag{6.9}$$

where,

PV = present value of the money invested;
FV = future value of the money invested;
r = annual interest or discount rate (in decimal notation);
n = number of years that the value will be discounted over.

This is the reverse of the FV formula talked about earlier. It should be noted that the fraction $1/(1+r)^n$ is also called the *discount factor*.

Suppose we have to decide between two possible options for rehabilitating an abandoned area to reduce the environmental impact: the first is an industrial development project, and the second is reforestation. Investment in the former will most likely yield benefits in the first years, whereas investment in the latter may generate benefits only after 30 years. Let us assume for simplicity sake, that both projects yield the benefit in one shot but in different years: the industrial development project in Year 3 and the reforestation project in Year 30. We assume also that the net benefits of the industrial development project are worth $3,000 and those of the reforestation project $15,000.

With a positive discount rate of 8 %, the present value of the two investments, using the formula presented above, will be $2,381.50 and $1,490.66 respectively. It follows that despite the higher benefits generated by the reforestation project, the industrial development project has a higher present value. The above example explains why environmental projects are seldom put first in the development agenda.

6.5.8 *Net Present Value*

Net present value (NPV) is another term used widely as an important profitability indicator of evaluating project investment proposals. The present value rule states that a project should be approved for execution only if the present value of the cash flow it generates in the future exceeds the present value of its cost, that is, if it has a positive net present value. For any investment opportunity, NPV of the future cash flow is the difference between all cash-inflow in the future and all cash-outflow in the future, taking time and discount rate into consideration.

$$NPV = \sum_{n=0}^{n} \frac{CF}{(1+r)^n} = Net\,Cash\,Flow/(1+r)^n \tag{6.10}$$

Suppose we have an environmental protection project that will require an investment of $1,0000,000. The project has estimated cash inflows of $750,000 per year for the next three years and $500,000 at the end of the fourth year. If we calculate the present value for these cash flows at the interest rate of 10 %, we end up with the numbers in Fig. 6.10.

In the example shown in Fig. 6.10, the net cash flow at the end of the four year is $1,750,000. This is a pretty good return on a million dollar investment. Notice that the net cash flow is the sum of cash inflows (revenue) and cash outflows (expenses). Suppose we adjust the cash flows to their present values, the net present value (NPV) will be $1,377,399. As can be seen in Fig. 6.10, the value is substantially less than $1,750,000 that we had without adjusting the future values for present values. It is important to note that this adjustment is crucial for anticipating the cash flows that actually occur in environmental projects. It is also real in the sense that most companies depend on borrowed money or investors fund for their working capital. It is expected that these companies will be required to pay something in form of interest for the use of these funds. When a project is conceived, it is expected to generate some future returns on investment, either in cash or in kind. In alignment with the

Fig. 6.10 Example of cash flow adjusted to present value

Time from Now	Cash Flow	PV Calculations PV = F/(1+r)^n	Present Value
Year 0	-$1,000,000	-1000000	-$1,000,000
Year 1	$750,000	$750,000/(1+0.1)1	$681,818
Year 2	$750,000	$750,000/(1+0.1)2	$619,835
Year 3	$750,000	$750,000/(1+0.1)3	$563,486
Year 4	$500,000	$500,000/(1+0.1)4	$512,260
NCF =	**$1,750,000**	**NPV =**	**$1,377,399**

NCF compared to NPV

concept of *time value of money* discussed earlier, the value of money received in the future will be worth less than money received today and, hence, should be adjusted to something less at present.

6.5.9 Profit-to-Investment Ratio

Another useful analysis variable is the profit-to-investment ratio (PIR). Some analysts prefer to call it return on investment (ROI) or *Profit per Dollar Invested*. This profitability indicator tells how much profit is expected over and above each dollar investment. Even though different companies may calculate this type of parameter differently, if the same investment prospects were to be with the different methodologies, the ultimate ranking would be comparable. For the purposes of environmental projects, the ratio will compare the Present Value of the cash profit from the environmental projects (cash flow from the industrial operations excluding capital) to the present value of the capital investments. An example of this calculation method follows in Table 6.4.

In the example shown above, \$5,000 was invested at the end of year 1, which has a PV of \$4,630. The cash flow from the operations totalled \$6,750 with a PV of \$5,568 and the total net cash flow (cash flow from the operations less investments) was \$1,750 with PV of \$938.

From the Profit-to-Investment Ratio, it can be seen that for every PV dollar of investment the project will generate \$1.20 of PV profits, i.e.,

$$PIR = PV\,Cash\,inflow/PV\,Cash\,outflow = \$5{,}567.71/\$4,630 = 1.20 \tag{6.11}$$

Table 6.4 Profit-to-investment ratio calculations

Year	Investment (cash outflow)	Income (cash inflow)	Net cash flow	Present value at 8 %		
				Cash outflow	Cash inflow	NCF
1	\$ 5,000.00	\$ 1,500.00	−\$ 3,500.00	\$ 4,630.00	\$ 1,388.85	−\$ 3,241.15
2		\$ 2,000.00	\$ 2,000.00		\$ 1,714.58	\$ 1,714.58
3		\$ 1,750.00	\$ 1,750.00		\$ 1,389.09	\$ 1,389.09
4		\$ 1,000.00	\$ 1,000.00		\$ 734.95	\$ 734.95
5		\$ 500.00	\$ 500.00		\$ 340.24	\$ 340.24
Total	\$ 5,000.00	\$ 6,750.00	\$ 1,750.00	**\$ 4, 630.00**	**\$ 5, 567.71**	\$ 937.71

6.5.10 Internal Rate of Return

The rate of return of a project is the return earned on an investment from the project's cash flow. The internal rate of return (IRR) is defined as that interest rate, which would make net present value (NPV) equals zero. This is the interest rate, which would simply allow the company to break even on the project. That is the reason why some authors (e.g., Campbell et al. 2001) called it breakeven discount rate (BDR). IRR is the most difficult equation of all the cash flow techniques and should therefore be performed on financial calculator, or computer using the Excel spread sheet.

Thus we require a value for "r" such that:

$$NPV = \sum_{n=0}^{n} \frac{Cash\ Flows}{(1+r)^n} = 0 \tag{6.12}$$

From the example shown in Table 6.5, a five-year project has a cash flow that provides an ultimate \$1,750 net cash flow (or profit) at the end of the project. When cash flow is discounted at the interest rate of 23.75 % the NPV is found to be zero. Therefore, the IRR of this project is 23.75 %.

Equation 6.12 can be expanded as follows, plugging in the numbers from Table 6.5:

$$NPV = -\frac{3{,}500}{(1+r)^1} + \frac{2{,}000}{(1+r)^2} + \frac{1{,}750}{(1+r)^3} + \frac{1000}{(1+r)^4} + \frac{500}{(1+r)^5} = 0 \tag{6.13}$$

The IRR method represents the interest rate that could be paid on the investment, which would bring the projects cumulative cash flow to zero at the end of the project life. For this reason, it is sometimes called "discounted cash flow rate of return" (DCF ROR). It also approximates the return a company could claim for ongoing operations if profits could be continually reinvested in new projects with comparable returns.

The internal rate of return is a useful measurement tool for comparing different investment opportunities, since it considers the time value of money and provides information on the level of profitability.

Table 6.5 Internal rate of return calculations

Year	Net cash flow	Cash flow discounted @					
		10 %	15 %	20 %	23.75 %	25 %	30 %
1	−\$ 3,500.00	−\$ 3,181.82	−\$ 3,043.48	−\$ 2,916.66	−\$ 2,828.28	−\$ 2,800.00	−\$ 2,692.31
2	\$ 2,000.00	\$ 1,652.89	\$ 1,512.29	\$ 1,388.88	\$ 1,305.99	\$ 1,280.00	\$ 1,183.43
3	\$ 1,750.00	\$ 1,314.80	\$ 1,150.65	\$ 1,012.72	\$ 923.43	\$ 896.00	\$ 796.54
4	\$ 1,000.00	\$ 683.01	\$ 571.75	\$ 482.25	\$ 426.40	\$ 409.60	\$ 350.13
5	\$ 500.00	\$ 310.46	\$ 248.59	\$ 200.93	\$ 172.28	\$ 163.84	\$ 134.66
Total	\$ 1,750.00	\$ 779.34	\$ 439.80	\$ 168.12	**\$0**	−\$ 50.56	−\$ 227.55

6.5.11 Present Worth Ratio

Present worth ratio (PWR), also known as present value per dollar invested (PV/$) is the economic indicator used routinely in analysing investment projects. Present worth ratio is calculated by dividing the present value of the net cash flow (PVNCF) by the present value of the investment (PV Investment). This is shown as follows:

$$PWR = \frac{PVNCF}{PV\,Investment} = \$937.71/\$4630.00 = 0.20 \tag{6.14}$$

Present worth ratio is calculated using the data shown in Table 6.6.

The PWR is a parameter, which is most often used as budget ranking tool in situations when not enough capital funds are available to invest in all available worthy investment opportunities. PWR helps to choose the most profitable projects from the inventory of opportunities and to maximise the present worth at a selected discount rate.

Table 6.6 illustrates how to rank and choose environmental projects to invest in, by means of PWR at an 8 % discount rate, if limited funds were available.

The eight environmental projects are worthy of investment. However, due to limited availability of funds and with the objective of maximising present value, we have ranked all of them using the present worth ratio at 8 % discount rate and would choose projects C, G, E and H as shown in Table 6.7:

The four projects selected require a total of $19 million investment with a potential present value benefit of $29 million. The average present worth ratio for the four selected projects is 1.88. No greater returns can be earned with any other combination from the eight investment projects under review.

Table 6.6 Ranking environmental projects by NPV and PWR in chronological order from the highest to the lowest value

Environmental	NPV @ 8 %	PV @ 8 %	PWR @ 8 %	Ranking by NPV	Ranking by PWR
Project ID		Investment	(PV/$)		
A	$ 938,000.00	$ 4,630,000.00	0.20	8	7
B	$ 1,200,000.00	$ 10,000,000.00	0.12	7	8
C	$ 3,000,000.00	$ 1,000,000.00	3.00	5	1
D	$ 9,000,000.00	$ 7,000,000.00	1.29	2	5
E	$ 6,000,000.00	$ 4,000,000.00	1.50	3	3
F	$ 2,000,000.00	$ 5,000,000.00	0.40	6	6
G	$ 5,000,000.00	$ 3,000,000.00	1.67	4	2
H	$ 15,000,000.00	$ 11,000,000.00	1.36	1	4

Table 6.7 Selecting environmental projects with the highest NPV using PWR

Rank	Environmental Projects ID	PWR @ 8 % (PV/$)	Investment Required	Net present Value
1	C	$ 3.00/$	$ 1,000,000.00	$ 3,000,000.00
2	G	$ 1.67/$	$ 3,000,000.00	$ 5,000,000.00
3	E	$ 1.50/$	$ 4,000,000.00	$ 6,000,000.00
4	H	$ 1.36/$	$ 11,000,000.00	$ 15,000,000.00
Average		$ 1.88/$		
Total			$ 19,000,000.00	$ 29,000,000.00

6.6 Concluding Remarks

The focus of this chapter is on developing a methodology which can be used in evaluating the merits of technologies both from an economic as well as environmental point of view. Neither cost-benefit analysis nor any other method can provide ethically neutral measures of how important an environmental change is for society. This is true even if we consider only small changes that do not substantially affect the income distribution or relative prices. How important an environmental project is for society is, essentially, a normative question. An analysis based on specific normative premises cannot, at the same time, be ethically neutral.

Still, policy choices must, of course, be made. It is our belief that economic analysis can be more useful if, rather than explicitly ranking projects according to their social desirability (e.g., profit-to-investment ratio, internal rate of return or present worth ratio), it is limited to the task of being systematically descriptive. The central question for the analyst is then not which project is best, but rather what information is most important for decision-makers.

Will the environmental aspect be forgotten unless one attaches a price tag to it? That is, of course, possible. If one really believes that economic evaluation increases the probability that decision-makers will take environmental considerations into account, this is a strong argument for monetary valuation. Nevertheless, this reasoning may be overly optimistic about the influence of such price tags on the environment. What is needed to secure environmental protection, in our opinion, is economic incentives and institutions; we need carbon taxes, tradable emission permits, subsidies to local communities protecting rare species, subsidies to development of new climate-friendly technologies, etc. To protect the environment, we should focus our attention on the factors affecting actual behaviors of consumers, firms, local communities, and governmental agencies in their everyday activities.

In this spirit we have tried to present an approach that will hopefully balance the benefits of economic prosperity, environmental protection and social enhancement, using the materials balance model shown in Fig. 6.7.

References

Ackerman F, Heinzerling L (2002) Pricing the priceless: cost-benefit analysis of environmental protection. Univ Pa Law Rev 150:1569

Asafu-Adjaye J (2009) Environmental economics for non economists: techniques and policies for sustainable development, 2nd edn. World Scientific Publishing Co., Pty. Ltd, Singapore

Boer B, James D (eds) (1990) Property Rights and Environment Protection, Environment Institute of Australia

Callan SJ, Thomas JM (2007) Environmental economics and management, theory, policy and applications, 4th edn. Thompson, South Western

Campbell JM et al (2001) Analyzing and managing risky investments, 1st edn. John M, Campbell, Norman

Clarke S (18 November 2009). Australia leads world in carbon emissions. ABC News (Australian Broadcasting Corporation). Accessed 17 Dec 2013

De Steiguer JE (2006) The origins of modern environmental thought. University of Arizona Press, Tucson, 246 p

Erkman S, Ramaswamy R (2001) Industrial ecology as a tool for development planning. Case Studies in India, Sterling Publishers et Paris: Editions Charles Leopold, New Delhi

Farnham PG (2010) Economics for Managers, 2nd edn. Pearson Education, Harlow

Hanley N, Spash CL (1993) Cost-benefit analysis and the environment. Edward Elgar, Cheltenham, pp 1–8

Hundloe T, McDonald GT, Ware J, Wilks L (1990) Cost-benefit analysis and environmental impact assessment. J Environ Impact Assess Rev 10(1–2):55–68 (Peer Rev J)

Lauder S (11 September 2009) Australians the world's worst polluters. ABC News (Australian Broadcasting Corporation). Accessed 17 Dec 2013

Perman R (ed) (2003) Natural resources and environmental economics. Pearson Education, Harlow

Smith A (1776) The weath of nations. Random House Inc., New York

Taylor M (2014) Global warming and climate change: what Australia knew and buried...then framed a new reality for the public, ANU Press, Canberra, 215 p

Tobin H (15 June 2012) Carbon tax will cripple australian coal industry: new study. Media release. Institute of Public Affairs. Accessed 17 Dec 2013

WCED (1987) World commission on environment and development: our common future (the Brundtland Report). Oxford University Press, Oxford

Chapter 7
Environmental Risk and Decision Analysis

"Kto ni riskuet, tot ni piot champanskoe"; Engl. trans. "He who doesn't drink never gets to drink champagne"
—An old Russian proverb

7.1 Introductory Remark

Environmental risk deals with the probability of an event causing a potentially undesirable effect. Environmental risk assessment thus deals with the statistics (both qualitative and quantitative), because probability is the mathematical measure of risk, and with hazard assessment, which determines the nature of the undesirable effect.

The increasing importance of environmental quality to the economy, human health, and ecosystems has influenced a number of recently formulated national environmental risk assessment/risk management frameworks, particularly as command-and-control instrument has failed to deliver adequate outcomes (Power and McCarty 1998). Concern about increasing atmospheric concentrations of green house gases, e.g., carbon dioxide, methane, nitrous oxide and the potential impact of these increases on the earth's climate has grown significantly over the last decade. Many countries, particularly the developing countries, wrestle with balancing economic development and meeting critical near-term environmental goals while minimizing long-term environmental risks. From an environmental point of view, emission of carbon dioxide to the atmosphere is the most serious potential problem. An example of this is the 1986 Lake Nyos gas (CO_2) eruption that took place in Cameroon, West Africa (see Chap. 1, Fig. 1.6).

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7.2 Perceptions of Risk

The word "risk" often carries a negative connotation, which is why most people tend to focus on the negative effects (or downside potential) of risk, which should be mitigated or avoided as much as possible. However, having such belief means opportunities, i.e., the upside potential of risk, may be missed out. A negative risk may be defined as the likelihood of a specific type of threat, hazard or harm caused over a given time period. Threat is an intrinsic property of substance, which is activated upon an event.

On the other hand, risk can be possible by providing an opportunity for an organisation, community or a country. Real options theory has been recognised as a risk assessment tool that considers the opportunity component of risk. Many authors (e.g., Damodaran 2008; Kodukula and Papudesu 2006; Mun 2012; Schulmerich 2008) have argued in favour of real options as the best approach that gives prominence to the upside potential of risk, based on the fact that uncertainty can sometimes be a source of additional value, especially to those who are poised to take advantage of it. For example, consider the risk of diving into deep shallow water. The shallow water itself constitutes a hazard. The act of diving is the event that precipitates the risk. The consequence can range from severe such as death by drowning, to mild such as cuts and scratches. On the other side of the coin, the consequence may be the discovery of a gold treasure under the shallow water, which in turn, becomes an opportunity. Thus, the concept of risk has two components: the probability or likelihood that an event will occur and the economic consequences of the event, if it does occur.

Risk is characterised by three main factors (risk event, probability and consequence) and provides an answer to four key questions (Kaplan and Garrick 1981):

1. **Risk event**: What can go wrong? (i.e., precisely what might happen to cause an environmental threat or hazard?)
2. **Risk probability**: How likely is it to happen? (i.e., what is the likelihood or frequency of risk event occurring?)
3. **Amount at stake**: What are the consequences? (i.e., the extent of loss or gain, which could result)
4. **Risk response strategy**: What can we do about it? (i.e., do we reduce the likelihood or the impact?; do we accept, mitigate, transfer or avoid the risk?)

Using the combination of the three factors, risk event is calculated by the following relationship:

$$\text{Risk event} = \text{Risk probability} \times \text{Consequence (e.g., economic value add, NPV or net benefit)}$$

Risk probability is the extent to which an event is likely to occur. This is measured by the ratio of the favourable cases to the whole number of cases possible. Risk is, therefore, a function of both the likelihood and the consequence of a specific threat being realized (Borge 2001).

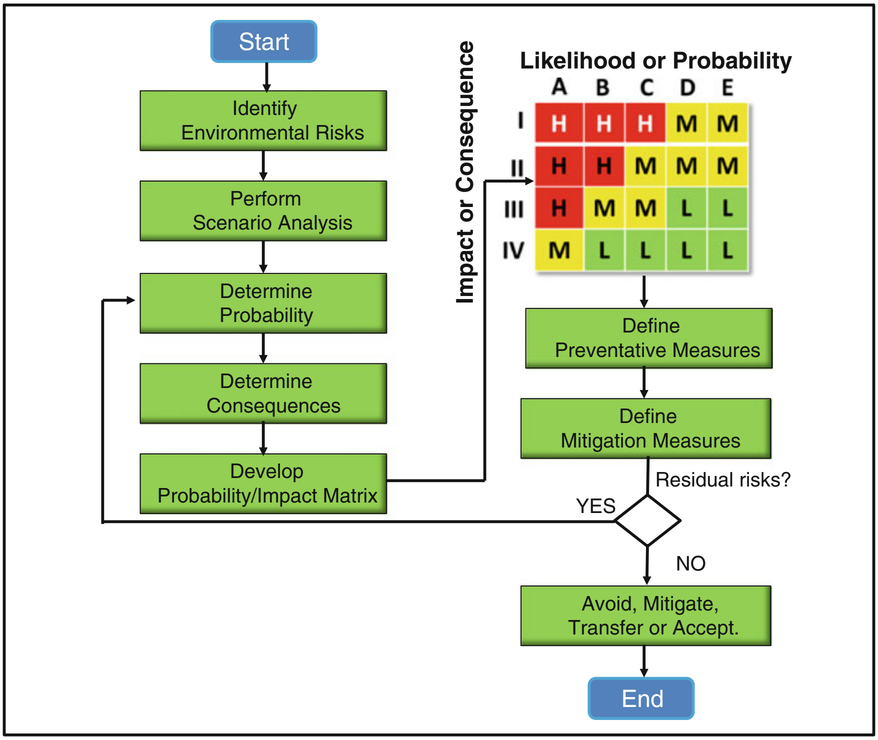


Fig. 7.1 Environmental risk management framework, showing risk identification, qualification, mitigation, and response processes

An effective risk management process, as narrated in Standards Australia (2006), consists of the key elements identified in Fig. 7.1. One method for performing this process is through a scenario-based risk assessment tool that utilizes the risk-matrix approach to characterize the probability and consequence of potential impacts associated with a particular project activity.

Using this type of approach provides a consistent method for defining the likelihood of risk occurrence and potential impact to the environment. Following a structured process such as this allows better understanding of risks and results in better informed risk-based management decisions, ranging from complete mitigation to acceptance of the risk and everything in between.

7.3 Structuring an Environmental Decision Problem

Making thoughtful decisions about environmental challenges that involve high risk, safety assurance and potentially irreversible consequences is of profound importance for current and future generation. The answers to the following questions, taken together, can provide some of the basic information required to determine whether the best and well thought-out environmental decision (e.g., carbon sequestration and storage) is being made (see e.g., Deel et al. 2007);

- how much CO_2 will be injected, at what rate, and over what period?
- into what geologic formation will the CO_2 be injected?
- what alternative sites were considered for CO_2 storage and injection?
- what studies were conducted of the storage reservoir and the alternatives?
- how will the CO_2 be trapped in this formation and are there any evidence that the trapping will be effective?
- what seals exist between the storage formation and any usable groundwater?
- what monitoring activities during and after injection will be conducted and by whom will those be performed?
- who will be liable for leaks and what will be done by whom to fix any detected leaks both during and after injection?
- what precautions will be taken at project closure to ensure continued safe storage?
- what aspects of the project are regulated and under what regulatory authority?

Addressing the set questions identified above involves weighing benefits and costs in multiple dimensions. In spite of the high stakes of the intergovernmental panel on climate change (IPCC), governments of various countries often fail to take systematic account of the environmental consequences in its actual decision-making and instead, follows standard operating procedures, policies, existing legislative mandates, or simply muddles through (IPCC 2005). One tool that has been used to support environmental decision-making is the simple multi-attribute rating technique (SMART), using decision trees (see e.g., Edwards 1997; Kamenetzky 1982; von Winterfelt and Edwards 1986; Wakeman 2003).

Decision analysis consists of a set of mathematical and organisational tools that help a decision maker think systematically about complex problems and improve the quality of the resulting decisions (Clemen 1991). In any decision analysis problem, there are essentially three possible elements: *decision or choice options*, *chance event*, and *outcome values* (see e.g., Havranek 1999; Schuler 2001). A decision maker has no control over whether or not a certain chance event will occur. He also has limited control over the cost to perform corrective action if a certain negative event does occur. The only real control he has is over the choice of his decision. For example, on a carbon sequestration project, a decision maker may choose to implement a particular carbon storage sequestration mechanism such as structural or stratigraphic trapping where a low-permeability cap-rock stops CO_2 upward movement (Hesse et al. 2008), residual trapping where the injected CO_2 plume is split into disconnected micro-metre sized bubbles, which are surrounded by brine and immobilized by capillary forces (Juanes et al. 2006), solubility trapping where CO_2 dissolves in the formation brine and the heavier CO_2-enriched brine sinks in the reservoir because of gravity forces (Riaz et al. 2006), or mineral trapping where the dissolved CO_2 reacts with formation brine or host rock to form solid minerals (Gaus 2010).

If, for example, implementing structural trapping technology allows one to achieve carbon storage with zero leakage outcome within the estimated time frame, perhaps

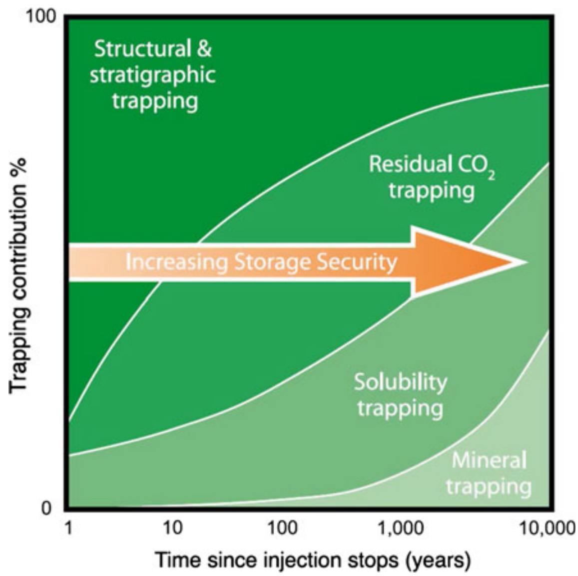


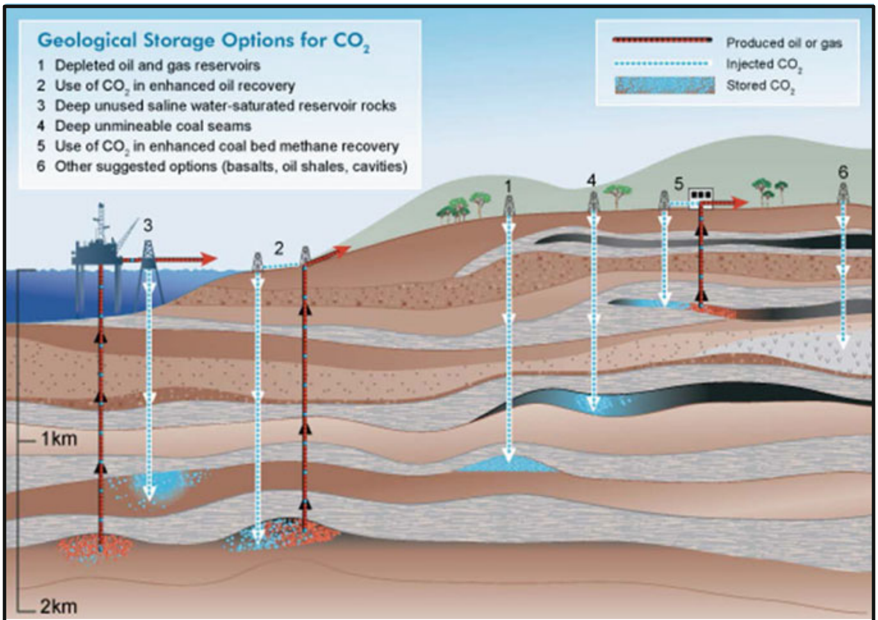
Fig. 7.2 CO_2 geological storage mechanisms as a function of time, showing various trapping technology and length of time it takes to store CO_2 without leakage

no additional decisions will be required (see Fig. 7.2). However, the leakage risk may be too high. At this point, he has new decisions to make, such as storing the CO_2 in a depleted oil and gas reservoirs, injecting into pore spaces of sedimentary rocks for enhanced oil recovery (EOR), storing in a deep unused saline reservoir rocks, and so on (see Fig. 7.3), or simply seek approval from a regulatory agency to flare the gas and bear the consequence, e.g., by paying huge carbon tax levy!

The above analysis illustrates the sequential nature of decision that must be captured in a CO_2 sequestration problem.

7.3.1 Decision Tree

A decision tree is a graphical device for analyzing project situations under risk and uncertainty. Reflecting the decision process (see e.g., Fig. 7.5), the tree displays a strategic road map in the form of the branches of a tree, from left to right, indicating alternative decision options, their associated costs, their possible outcomes (e.g., success versus failure), the probability and the payoff of the outcomes. The way to evaluate decisions is to calculate the expected value of each path, folding the tree back from the end points to the initial decision point (Kahneman and Tversky 1979; Milosevic 2003). A rational decision maker uses expected monetary value (EMV) to make an informed decision.



This figure shows various types of geological storage .
For example, Well number 1 in the figure shows buoyant CO_2 being contained in a small region by the shape of the reservoir (structural trapping) and the caprock above.

(Source: IPCC, 2005)

Fig. 7.3 Types of geological storage sites for CO_2

7.3.2 The Concept of Expected Monetary Value

Expected Monetary Value (EMV) is probably the first statistical concept that has been widely used in risk analysis, and this statistical concept forms the cornerstone of decision analysis (Schuler 2001). EMV can be defined as the analysis of uncertainties in the probability estimates. Some authors (e.g., Cambell and John 2001) call it *risk weighting value (RWV)*. Others (e.g., Hall 2007; Harding 2008; Kahneman and Tversky 1979) defined it as the probability-weighted average of the gain (chance of success) relative to the loss (chance of failure).

7.3.3 Analyzing a Basic Risky Decision with a Decision Tree

A basic risky decision is one that involves a single decision, one uncertain event, and one outcome value (e.g., payoff, NPV, ROI, etc.), which is affected by both. Consider a simple example of a risky decision analysis between two choices: to develop a new

Decision Definition	Decision Node	Chance Node	Outcome Node
Test new CO_2 sequestration technology or do nothing.	**Input:** Cost of each decision **Output:** Decision made	**Input:** Scenario probability, reward if occurs. **Output:** EMV	**Computed**: Payoffs minus costs along paths

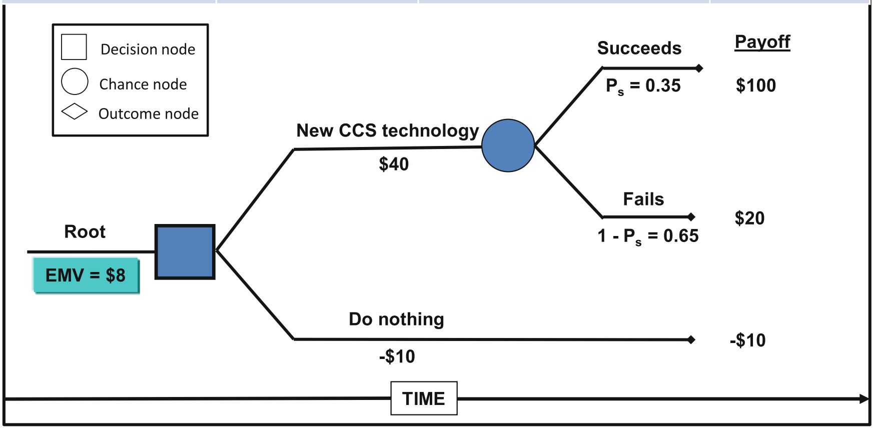


Fig. 7.4 A Simple decision tree with one decision node and one chance node

technology for carbon capture and storage or to flare the carbon dioxide, i.e., do nothing (see Fig. 7.4).

There are two branches emanating from the choice node. One branch references geological storage technology option, while the other branch references gas flaring option. The total estimated cost for development, installation, operation, maintenance and monitoring of the carbon, capture and storage (CCS) technology is estimated to be $40 million (if the project succeeds). This amount is shown beneath the branch for new CCS technology. The estimated pollution cost for gas flaring (carbon tax and air quality, etc.) is $10 million. After consulting with subject matter experts (SME) in the area of carbon sequestration technology, the environmental manager concludes that there is 35 % chance that the new CCS technology will be effective and alleviate the problem of environmental pollution. The decision tree for the basic risky decision is illustrated graphically in Fig. 7.4.

Note the key elements in the decision tree. First, only the chance or event nodes represent uncertain outcomes and have probabilities attached to them. Second the decision node represent a choice, which is called the *root*. Third, the *outcome node* or sometimes called the *end node* is shown on the decision tree as a rectangle. On a pure expected-value basis, the best option is to develop a new CCS technology because expected monetary value associated with this option is $8 million greater than capturing and flaring the gas into the atmosphere, which has a sunk (pollution) cost of $10 million.

The simple decision tree shown in Fig. 7.4 can be used as a framework for performing any complex and multi-criteria decision analysis. The carbon storage and flare relationship can also be expressed mathematically as shown in Eq. (7.1)

$$EMV = P_s * (VOS) + (1 - P_s) * (VOF), \tag{7.1}$$

where:

- VOS = Value of success;
- (P_s) = Probability of success;
- VOF = Value of failure;

In Fig. 7.4, the EMV was calculated using Eq. (7.1).

$$EMV = 0.35 * (\$100 - \$40) + (1 - 0.35) * (\$20 - \$40) = \$8. \tag{7.2}$$

7.3.4 Analyzing CO_2 Sequestration Options with a Decision Tree

To illustrate the steps involved in developing a complex decision tree, let us consider the analysis of a geological storage options for CO_2 as shown in Fig. 7.3. For simplicity sake, we will select the first three options. The decision analysis for geological storage options is broken down into three phases. Assume that we are provided with the additional information on each of the three phases:

1. Phase 1 is expected to cost \$50 million and planned to last for one year. There is a 70 % chance of completing the first phase successfully.
2. In phase 2, public opinion and feedback will be gathered and environmental impact assessment conducted over a two-year period. This phase will cost \$100 million, and the outcome of this phase will determine whether or not to move ahead to the next phase. There is only 30 % chance that option 1 (storage of CO_2 in depleted oil and gas reservoirs) will prove successful, but there is 10 % chance that it will be successful if option 2 (use of CO_2 in enhanced oil recovery) is employed, and a 10 % chance that it will succeed only in option 3 (CO_2 storage in an unused saline water-saturated reservoir rocks).
3. In phase 3, this is the final investment decision (FID) phase, where the project will expand to the long-term consequences of injecting and storing CO_2 in depleted

Table 7.1 Cost and benefit of developing CO_2 sequestration options: cost represents the capital expenditure for carbon sequestration, while benefit represents the NPV

CO_2 geological storage options	Cost of development	NPV calculations
Depleted oil and gas reservoirs	\$500 million	\$400 (PVA, 10 %, 7 years)
Use of CO_2 in enhanced oil recovery	\$500 million	\$125 (PVA, 10 %, 7 years)
Storage of CO_2 in reservoir rocks	\$600 million	\$300 (PVA, 10 %, 7 years)

oil and gas reservoirs. If all engineering designs are successfully completed and CO_2 sequestered, using option 1 or 2, the cost will be \$250 million and last for four years. There is an 80 % chance of success, if option 1 or option 2 is chosen. However, if option 3 is chosen, the cost will be \$300 million and will also last for four years. With this option, there is a 75 % chance of success.

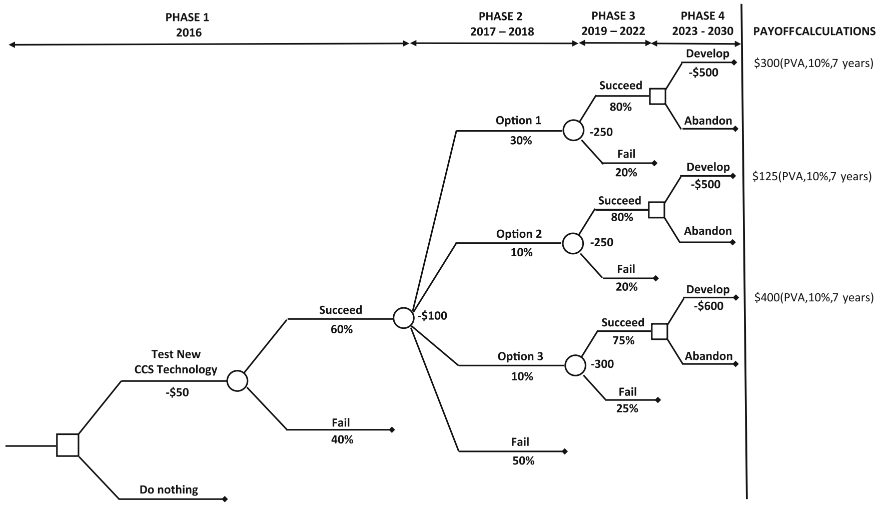


Fig. 7.5 Decision tree for carbon capture and sequestration project evaluation, specifying the phases, the cash flow at each phase, the probabilities and the payoff calculations

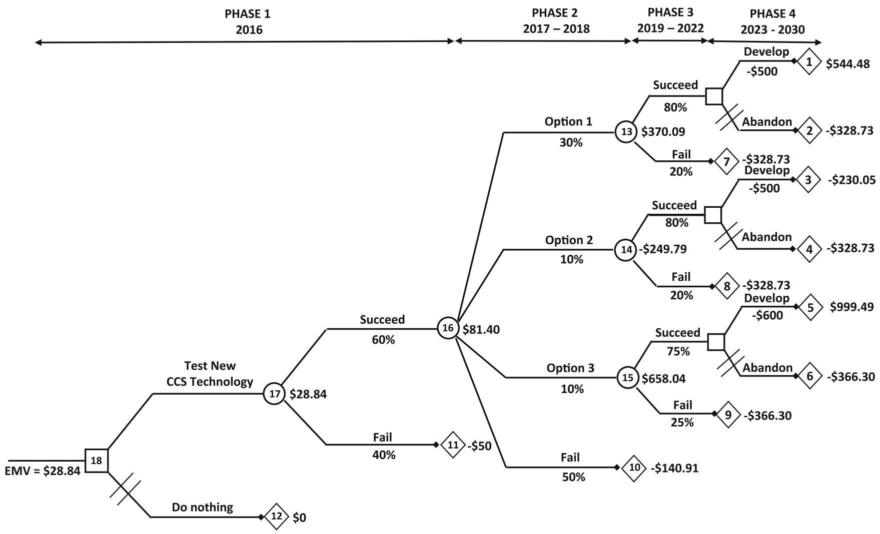


Fig. 7.6 Carbon sequestration decision tree folded back

Table 7.1 shows the costs of developing the CO_2 sequestration options and the annual cash flows if the project passes through all the three phases.

We now have the information to draw the decision tree for carbon sequestration project development. We will first draw the tree in Fig. 7.5, specifying the phases, the NPV at each phase, and the associated probabilities. The expected monetary value of the carbon sequestration project, given the uncertainty over its success is $28.84 million (see Table 7.2). This value reflects all the possibilities that can unfold over time and shows the choices at each decision branch that are optimal and thus be rejected.

The decision tree in Fig. 7.5 shows the probabilities of success at each phase and the marginal cashflow or benefits associated with each step. At each stage in the decision tree, judgment was made based on the marginal cash flow or NPV at that juncture. In the last step in the decision analysis process, the expected values are computed by working backward through the tree and estimating the optimal action in each decision phase as shown in Fig. 7.6 and expected monetary value calculations

Table 7.2 Expected monetary value calculations

Outcome nodes	NPV calculations	Expected value
Node 1	$-50 - 100/1.1 - 250/1.1^3 - [500 - 300(\text{PVA}, 10\%, 7\text{ years})]/1.1^7 =$	$544.48
Node 2	$-50 - 100/1.1 - 250/1.1^3 =$	−$328.73
Node 3	$-50 - 100/1.1 - 250/1.1^3 - [500 - 125(\text{PVA}, 10\%, 7\text{ years})]/1.1^7 =$	−$230.05
Node 4	$-50 - 100/1.1 - 250/1.1^3 =$	−$328.73
Node 5	$-50 - 100/1.1 - 250/1.1^3 - [600 - 400(\text{PVA}, 10\%, 7\text{ years})]/1.1^7 =$	$999.49
Node 6	$-50 - 100/1.1 - 300/1.1^3 =$	−$366.30
Node 7	$-50 - 100/1.1 - 250/1.1^3 =$	−$328.73
Node 8	$-50 - 100/1.1 - 250/1.1^3 =$	−$328.73
Node 9	$-50 - 100/1.1 - 300/1.1^3 =$	−$366.30
Node 10	$-50 - 100/1.1 =$	−$140.91
Node 11	-50	−$50
Node 12	0	$0
Chance nodes	NPV calculations	Expected value
Node 13	$(544.48 * 0.8) - (328.73 * 0.2) =$	−$369.84
Node 14	$(-230.05 * 0.8) - (328.73 * 0.2) =$	−$249.79
Node 15	$(999.49 * 0.75) - (366.30 * 0.25) =$	−$658.04
Node 16	$(370.09 * 0.3) - (249.79 * 0.1) + (658.04 * 0.1) - (140.91 * 0.5) =$	$81.40
Node 17	$(81.40 * 0.6) - (50 * 0.4) =$	$28.84
Decision node	Test New CCS Technology; EMV = $28.84; or Do nothing; EMV = $0	
Node 18	Decision: Test New CCS Technology because EMV ($28.84) > 0	

in Table 7.2. Rolling back the decision tree allows a decision maker to see what the value of CCS option is at each phase in the process.

One very important use of a decision tree is that it is one way of analysing a complex decision and braking it down into a series of small parts, and then reassemble the parts to provide a rational basis for the initial decision, allowing for all unforeseen events and possible decision alternatives to be defined and analysed in a consistent and structured manner. This has been demonstrated in Fig. 7.5, showing a decision analysis on whether to test a new carbon capture and sequestration technology or do nothing.

In spite of the usefulness of decision tree analysis in assessing pollution risks, greenhouse gas effect and groundwater issues, it still has its limitations. The most critical is that it does not capture, and integrate the entire variability in uncertainty variables, which is necessary for complex risk and decision problems encountered in the environmental protection and remediation sectors. A risk management approach, using Monte Carlo simulation technique fills this gap. This will be discussed in Sect. 7.4.2.4.

7.4 Risk Management Approaches

In the preceding chapters, several parameters were discussed, which were either estimated or projected. Capital expenditure (capex), pollution costs, volume of wastes and pollutants were estimated. CO_2 levels, oil and gas prices, carbon tax levels, exchange rates on dollar, interest/discount rates were all projected.

The longer the expected project life, the more uncertain these cash flow and decision variables become. The present value (PV) factor discussed in Chap. 6 is useful in this regard, as it realistically places a lower significance on the future dollars (by discounting) and a higher weighting to more current dollars. A dollar today is preferred to a dollar tomorrow, remember the 'time value of money' concept. PV is a function of the prevailing interest (or discount rates). However, discounting alone cannot fully account for the complex risks and uncertainties in the environmental business. Over time, a number of risk analysis techniques have evolved (and developed) to assist decision makers in the field of environmental management. There are two distinct risk management approaches that have evolved. These are deterministic and stochastic approaches.

7.4.1 Deterministic Approach

Current methods for environmental risk assessment are mostly deterministic. This means environmental factors such as the toxicity of pesticides are treated as if they were fixed, and precisely known. But in the real world, factors such as toxicity are not fixed but variable. For example, the same pesticide could be more toxic to some species of wildlife, and less toxic to others. What's more, the factors affecting risk are not precisely known but uncertain. For example, toxicity is measured for only a very small number of species, so scientists have to estimate toxicity to all the other species that they want to protect. Examples of risk analysis, using deterministic approaches include sensitivity analysis, using spider, and tornado diagrams.

7.4.1.1 Sensitivity Analysis

The traditional approach to performing project risk analysis involves making judgments about "best estimate" or "most likely" values for each parameter under review, and using same in calculating "base case" evaluations. Through a combination of experience, intuition, judgment, and consensus, the analyst must then decide if the benefit exceeds the cost of investing in the project.

Sensitivity analysis shows the effect of changes in the key assumptions and the main key value drivers where attention should be focused. It helps answer the question, "what if?". The process of conducting sensitivity analysis entails on first deciding on the important output variables, like NPV, then changing the input variables that impact NPV. A common outline for addressing uncertainties or performing "what if" questions is presented in Table 7.3. The table forms the initial entry for spider diagram and Tornado diagram in Figs. 7.7 and 7.8, respectively.

The main disadvantages of sensitivity analysis is that it produces more information than is possible to convey effectively. Given that the ability to generate numbers exceeds the capacity to manage them, a more general format is helpful (Cambell and John 2001). Hence the need for a spider diagram.

Table 7.3 Example of environmental project sensitivity analysis used for developing spider and tornado diagrams

Input variables	Base case	Upside	Lowside
Volume of GHG emissions (units)	1,000	20 %	20 %
Sales price for LNG ($/unit)	5	6	15 %
Pollution cost ($/unit)	20	23 %	17 %
Discount rate (%)	0.8	20 %	0.5
Project delay (months)	0	15	−20
Capital expenditure ($million)	100	20 %	30 %
Operating cost ($million/year)	6	8.5	7 %
Carbon tax	0.35	0.5	40 %

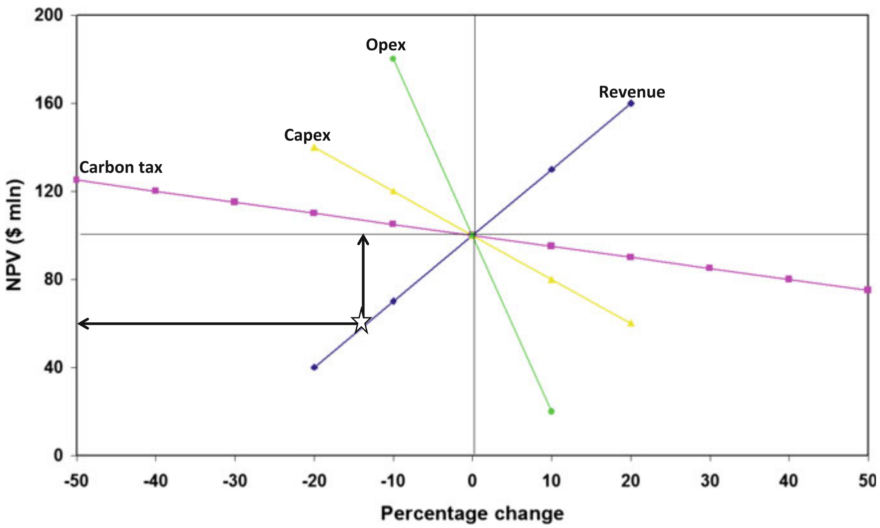
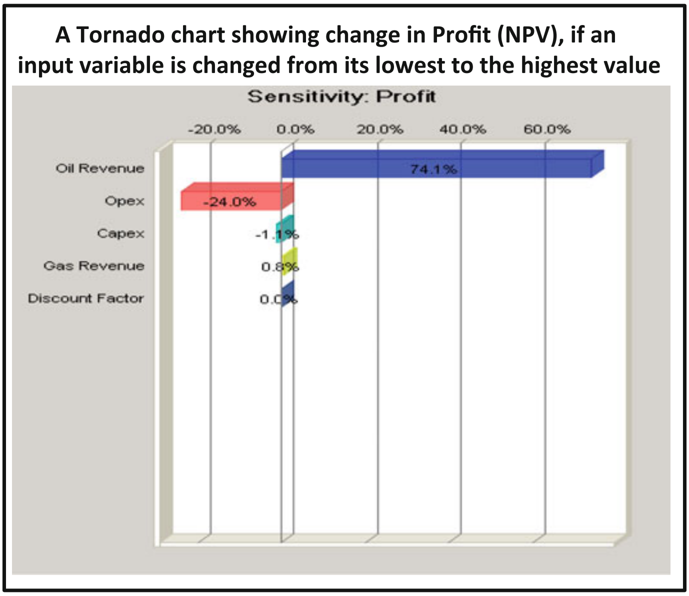


Fig. 7.7 Spider diagram illustration



Source: Sholarin, 2007

Fig. 7.8 Example of Tornado diagram

7.4.1.2 Spider Diagram

Spider diagram is a graph of the sensitivity of project value to several input values (see Fig. 7.7). The graph shows how sensitive the outcome criteria are to changes in individual input variables. The more sensitive they are to a variable, the steeper the slope of the variable.

Spider diagram is a popular way for displaying the impact of changing inputs on the desired output, NPV in the example. As shown in the illustrative diagram, the x-axis is a factor deviation from the base case. Although any dependent parameter can be used along the y-axis, it is recommended that an outcome value like the NPV, as in this illustrative case, be used for this analysis.

All lines of the graph go through the origin at 0 % change on the x-axis and a $0 change in NPV. This format allows direct measurement of the typical question: "how does NPV of an environmental project change if capital expenditure (capex) rises by 20 % or sales price for LNG fall by 15 %? For example, when sales price of LNG falls by 15 %, NPV declines by roughly 40 % (from $100 million to $60 million). Observe the star on two lines intersecting x-axis and y-axis on Fig. 7.7.

7.4.1.3 Tornado Diagram

Tornado diagram, as shown in Fig. 7.8, provides a decision analyst with an additional benefit of the combined effect of the variable range and the model sensitivity to that variable being expressed in one pictorial view. The technique, whether carried out manually or automatically (with a computer software, e.g., Toprank from the Palisades), involves running alternative what-if cases while changing one variable at a time. The variables are then prioritised in sequence of importance according to the range of the resulting outcome values. Displayed in the way shown in Fig. 7.8, the bars look like a tornado. Note that the top two variables account for most of the outcome uncertainty for that project case.

The key benefit of tornado diagram, as a form of risk analysis, is that it highlights the key project drivers and identifies areas to focus mitigation and management efforts required to enhance sustainable development success. However, it does not attempt to quantify the relative uncertainty in the different areas. This is still left to subjective qualitative interpretations of results.

In general, the main limitation of deterministic approach is that it does not allow for quantitative assessment of risk and uncertainty, i.e., it precludes making allowances for variations, which are necessary to compensate for unfavourable cases.

For this reason, an approach that further accounts for risks and uncertainty is necessary. This is stochastic or probabilistic approach.

7.4.2 *Stochastic Approach*

In the earlier section of this chapter, which deals with expected monetary value analysis, typically only two possible outcomes of a decision were considered, namely *success* or *failure*. However, the number of possible outcomes of any decision, are of course, infinite.

In this section, we consider a different and potentially more informative way of assessing and presenting environmental risk. Rather than trying to analyse an infinite number of possibilities or select only two outcomes, we could select a finite number to give a reasonable cross section of the outcomes which are possible.

Stochastic or probabilistic approaches enable variation and uncertainty to be quantified, mainly by using distributions instead of fixed values in risk assessment.

Stochastic analysis entails not only assessing the risk of failure, but also developing a statistical distribution of all possible outcomes (Harding 2008). A distribution describes the range of possible values (e.g., for toxicity), and shows which values within the range are most likely. The result of a probabilistic risk assessment can also be shown as a distribution, showing the range of environmental impacts that are possible, and which impacts within that range are most likely. This should provide a better basis for making decisions about pesticide risks, because the full range of possible outcomes can then be taken into account.

7.4.2.1 The Language of Risk

The language of risk is probability, which is expressed as a fraction between 0 and 1 or as a percentage ranging from 0 to 100 %. Probability provide a standardized way of describing any variable from any population, regardless of the units of the variable (e.g., density, volume, pressure, temperature, costs, years, etc.).

Several key words dominate the language of risk, which is expressed in form of statistical population. The basic ones include the following:

- ***Mean or Average***: the most often used parameter in a distribution and is the first moment. Other synonyms include *weighted average* and *expected value (EV)*. For example, the arithmetic mean for the score values shown in Table 7.4 is 9.67 (i.e., 87/9).
- ***Mode or Most Likely***: the mode is the value or group occurring with the greatest frequency. On a continuous distribution, the mode is the value at the peak of the probability distribution curve. For the score data in Table 7.4, a value of 8 occurs twice, while others occur only once; thus 8 is the mode or most likely value.
- ***Median or P50***: The median or 50th percentile is the middle observation after the data have been ordered from low to high. When an odd number of values exist, the median is the mid point. In case of an even number of values, the average of the middle two points should be used. For example, in Table 7.4, the median or P50 is (3, 5, 7, 8, **8**, 9, 10, 12, 25) or 8.

Table 7.4 Mean, mode, median and standard deviation

Score (x)	Mean (M)	Score − mean (D)	D_2
8	9.67	−1.67	2.7889
25	9.67	15.33	235.0089
7	9.67	−2.67	7.1289
5	9.67	−4.67	21.8089
8	9.67	−1.67	2.7889
3	9.67	−6.67	44.4889
10	9.67	0.33	0.1089
12	9.67	2.33	5.4289
9	9.67	−0.67	0.4489
87			320.0001
N = 9			40.00001
9.666667		Stand Deviation =	6.324556

- ***Standard Deviation***: shows how much variation or dispersion from the average exists. Comparing the mean, median, and mode provides information about the general shape of the curve; the greater the difference, the more asymmetrical the curve. Standard deviation, as shown in Table 7.4, is equal to 6.32. This is obtained by taking the square root of the *variance* or by using the following equation:

$$SD, \sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{N}(x_i - \bar{X})^2} \tag{7.3}$$

In normal distributions, the standard deviation for the first sigma range covers about 68.3 % of the area under the curve, the second sigma range captures about 95.4 % and the third sigma range covers almost 99.7 % of the area (see Fig. 7.10).

7.4.2.2 Probability Distribution Function

Since risks are associated with stochastic techniques, it seems natural that probability distribution functions are used to help describe the impact and probability of various risks associated with carbon capture, sequestration and storage. In probability theory, a probability distribution function (PDF) is a function that describes the relative likelihood for a continuous random variable to take on a given value.

Given a random experiment with its associated random variable X and given a real number x, let us consider the probability of the event $P(X \leq x)$. This probability is clearly dependent on the assigned value x. The probability distribution function (PDF) for the event can be expressed as follows (Soong 2004):

$$F_x(x) = P(X \leq x), \tag{7.4}$$

- where $F_x(x)$ = probability distribution function of an event occurring, the event being $(X \leq x)$.

The PDF is thus the probability that X will assume a value lying in a subset of S, the subset being point x and all points lying to the left hand side of x. As x increases, the subset covers more of the real line, and the value of PDF increases until it reaches 1. We can describe the probability distribution function shown in Fig. 7.9 in the form of a tabulation as shown in Table 7.5.

For example, let a discrete random variable X in Eq. 7.4 assume values −50, 100, 150, 200, 250, 300 with probabilities 0.1, 0.3, 0.6, 0.8, and 0.9 respectively. We then have probability distribution function for CO_2 sequestration option shown in Fig. 7.3 with several possible outcomes.

Figure 7.9 illustrates the situation in which carbon dioxide has been injected directly into underground geological formations (e.g., oil fields, gas field, saline formations, unmineable coal seams, etc.), but the CO_2 storage capacity and the outcome for each carbon sequestration options associated with those geological formations are uncertain.

Probability distribution function can take many different forms. They can be symmetrical or skewed. Figure 7.10 presents few that might be used in environmental risk analysis: triangular, uniform, normal and lognormal (or skewed) distribution. The

Fig. 7.9 A PDF for CO_2 sequestration with several possible outcomes

$$F_x(x) = \begin{cases} 0, & \text{for } x < -50 \\ 0.1 & \text{for } -50 \leq x < 100 \\ 0.3 & \text{for } 100 \leq x < 150 \\ 0.6 & \text{for } 150 \leq x < 200 \\ 0.8 & \text{for } 200 \leq x < 250 \\ 0.9 & \text{for } 250 \leq x < 300 \\ 1, & \text{for } x \geq 300 \end{cases}$$

Table 7.5 Derivation of cumulative probability distribution

Decision option	NPV	Probabilities	Cumulative probabilities	EV
Unknown–unknown	$< -\$50$MM	0	0	0
Oil/gas reservoir	\$50MM	0.1	0.1	\$5MM
Use of CO_2 in EOR	\$100MM	0.2	0.3	\$20MM
Deep saline rocks	\$150MM	0.3	0.6	\$45MM
Deep coal seams	\$200MM	0.2	0.8	\$40MM
Coal bed methane	\$250MM	0.1	0.9	\$25MM
Basalts, oil shales	\$300MM	0.1	1	\$30MM
Known–known	$\geq$\$300MM	0	1	0
	Expected monetary value =			\$165MM

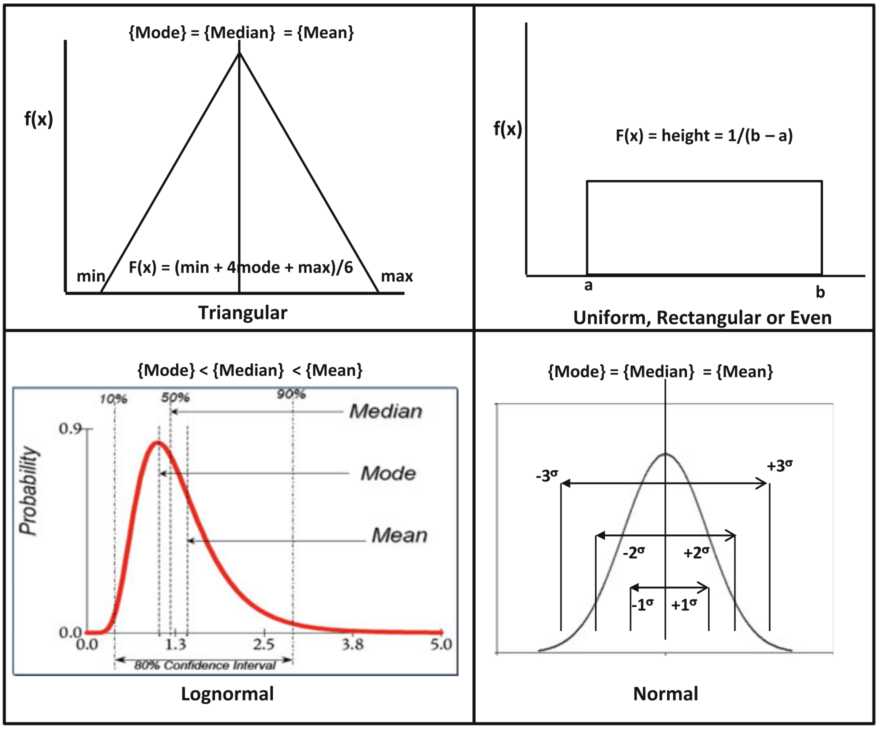


Fig. 7.10 Examples of common probability distributions

triangular distribution shows that probabilities increase uniformly from the optimistic point (minimum value) to a certain point where the highest probability is reached and then decrease uniformly until the pessimistic point (maximum value) is reached. In the normal distribution, the mean, median and most likely values are the same because distribution is symmetrical.

A special measurement, the standard deviation, relates specific ranges of values along the X axis with the probability that the actual value will be between the high and low value. Section 7.4.2.4 on Monte Carlo simulation discusses the application of these models.

7.4.2.3 Managing Uncertainty—The PERT Approach

Program evaluation and review technique (PERT) was developed in the 1950s by the United States Navy, while working on the Polaris Missile Program—one of the most complex engineering projects in history at the time—and needed a way to manage the project and forecast the project schedule with a high degree of reliability. It is a statistical way of predicting project completions when there is uncertainty about the project durations.

PERT, as distinct from the critical path method (CPM), discussed in Sect. 16.5.1, assumes each activity duration has a range that follows a *statistical distribution*. It was the first stochastic technique developed to mitigate risk in estimating project schedules. The technique uses three-point estimates or weighted average estimating method and simple equations to compute the expected duration and variance for each activity. Each activity in a PERT analysis must have three different durations estimated values. These are the optimistic, the pessimistic, and the most likely duration.

The activity's expected duration, variance, and standard deviation are calculated from these three values using the following formulas:

$$EV = \frac{(t_o + 4t_m + t_p)}{6}, \tag{7.5}$$

$$V = \frac{(t_p - t_o)}{6}, \tag{7.6}$$

$$SD = \sqrt{\frac{1}{6}(t_p - t_o)^2}, \tag{7.7}$$

where:

- EV = expected value for duration estimate,
- V = variance,
- SD = standard deviation,
- t_p = pessimistic duration estimate,
- t_m = most likely duration estimate,
- t_o = optimistic duration estimate.

For example, if the time required to clear an industrial waste is provided with an optimistic estimate of 40 weeks, pessimistic estimate of 60 weeks and the most likely estimate of 50 weeks, then the weighted average time estimate can be calculated as follows:

$$EV = \frac{(40 + 4 \times 50 + 60)}{6} = 50\ weeks \tag{7.8}$$

Using the pessimistic and optimistic estimates from the estimated duration calculation shown above, the standard deviation is determined to be:

$$V = \frac{(60 - 40)}{6} = 3.3\ weeks \tag{7.9}$$

$$SD = \sqrt{\frac{1}{6}(60 - 40)^2} = 1.83\ weeks \tag{7.10}$$

The PERT formula is based on a simplification of the expressions for the mean and variance of a beta distribution. The approximation formula for the mean is a simple weighted average of the three time estimates, with the endpoints assumed to be equally likely and the mode four times likely. Thus if the shape of the distribution is assumed to be positively skewed in the form of the beta distribution, then it is possible to estimate the mean and variance of the estimates using the graph and formula shown in Fig. 7.11.

Figure 7.11 shows what would be expected if the probability distribution of the expected dates for completing the project were to be plotted on a graph. On the left side of the diagram is the optimistic date for completing an activity. On the right hand side is the pessimistic completion date. The optimistic and pessimistic dates are the earliest and latest dates that are reasonable to complete an activity. Notice that the curve of the probability distribution is skewed to the right. This is because it is increasingly unusual for an activity to be performed earlier. The PERT weighted average is not the most likely date to complete an activity. It is shifted somewhat because the probability distribution is not symmetrical.

The three values, the expected value (EV), the variance, and the standard deviation (SD), are approximations that make it possible to predict the completion date for an activity and provide a range of values that determine the probability that the a particular activity will be completed within the range of values.

Using the example provided earlier, if the expected value for clearing an industrial waste is 50 weeks and the expected standard deviation is 1.83 weeks (see Eqs. 7.8 and 7.10), we could say that we have a 95 % chance that the project will be completed between 46 and 54 weeks.

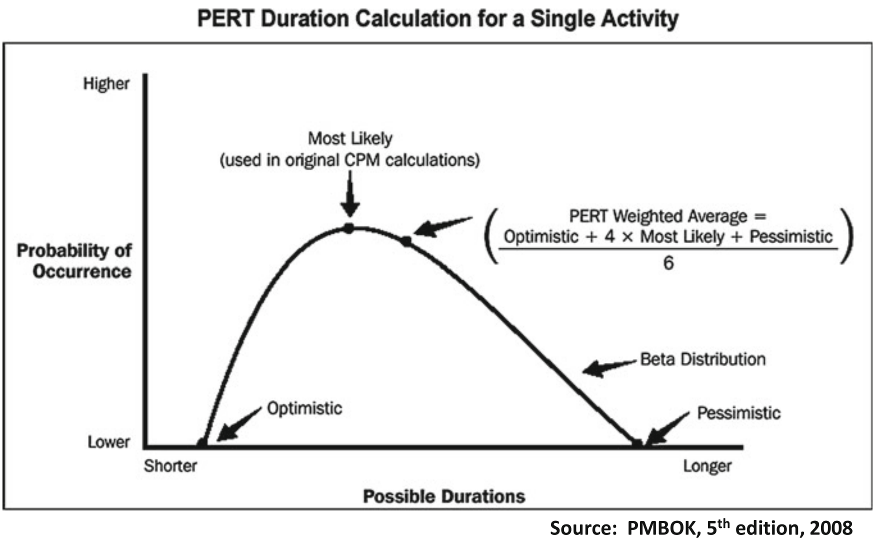


Fig. 7.11 PERT skewed probability distribution, using optimistic, pessimistic and most likely estimates

The standard deviation of the project completion is the sum of the standard deviations of the durations of the activities that make up the *critical path*. Since the duration of the activities on the critical path are the only ones that should go into the total that is the project duration, only standard deviation for activities on the critical path should be used to determine the standard deviation of the project completion date.

For illustration purposes, lets add estimated values for optimistic, pessimistic, and most likely to the network diagram shown in Fig. 7.12 (more details about network diagram is discussed in Chaps. 15 and 16). From these the expected value and standard deviation for project duration estimate can be calculated.

In order to get the standard deviation of the duration estimate for the entire project, it is very important to first square the standard deviation of each activity along the critical path and then sum up the value. As shown in Eq. 7.10, to calculate the standard deviation for each activity, simply subtract the optimistic duration from the pessimistic duration estimates and divide by six. For example, in Fig. 7.13, the square of the standard deviation of activities A, B, D, and F (written in bold) were summed up and then the square root of the total was taken to arrive at 0.705. The probability range of 95 % (the 2nd sigma) was achieved by subtracting and adding two standard deviations to expected value of the total project duration to get the range of values for the project duration, thus achieving 95 % probability of success in predicting the actual project completion date.

WBS ID	Optimistic Duration	Most Likely Duration	Pessimistic Duration
A	1	1	2
B	2	3	4
C	2	2	3
D	4	5	7
E	2	2	3
F	2	3	4

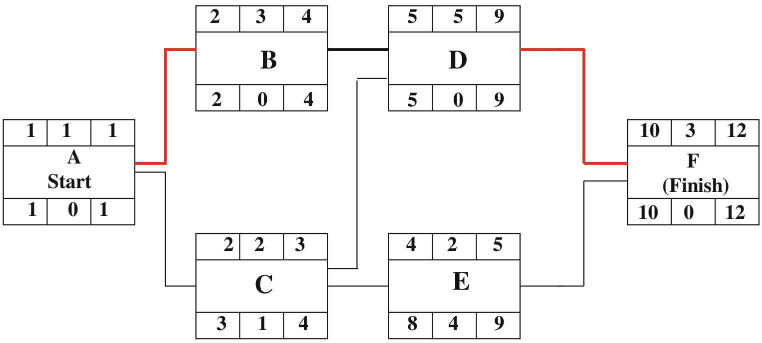


Fig. 7.12 PERT analysis using network diagram

WBS ID	Optimistic Duration	Most Likely Duration	Pessimistic Duration	Expected Value	Std. Dev	(Std. Dev)^2
A	**1**	**1**	**2**	**1.17**	**0.17**	**0.029**
B	**2**	**3**	**4**	**3.00**	**0.33**	**0.109**
C	2	2	3	2.17	0.17	0.029
D	**4**	**5**	**7**	**5.17**	**0.50**	**0.250**
E	2	2	3	2.17	0.17	0.029
F	**2**	**3**	**4**	**3.00**	**0.33**	**0.109**
			TOTAL	**12.34**	**Std. Dev**	**0.705**
95% Probability Range				**10.93 < EV < 13.75**		

Fig. 7.13 PERT calculations using probability range

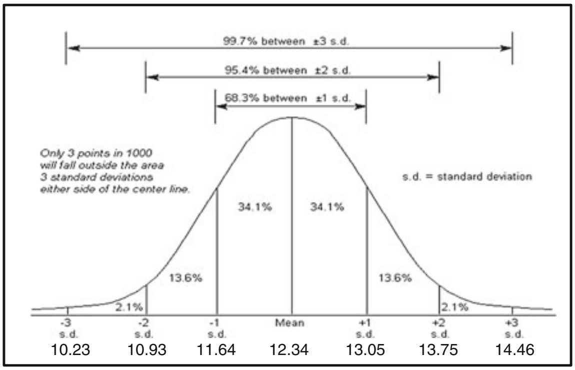


Fig. 7.14 PERT probability distribution with different standard deviations

Figure 7.14 shows the range of values, that is, plus or minus one, two and three standard deviations (i.e., 68.3 %, 95.4 %, and 99.7 % respectively) from the PERT weighted average (mean) value of 12.34. However, what if the actual durations of the entire project are such that a new critical path forms? It is not practically possible to provide an equation for the range of possible values that make up the project activity duration estimates. Instead, a computer simulation technique called Monte Carlo simulation can be used and is discussed in the next section.

7.4.2.4 Monte Carlo Simulations

Many of the risk analysis techniques employed for environmental risk assessment are aimed at expressing an anticipated outcome or economic value of the project. But most seem to be inadequate in providing a complete uncertainty description. There are many reasons why Monte Carlo simulation is a more sophisticated and preferred risk analysis technique.

Firstly, expected value (EV) method is a deterministic approach. Even when based on decision tree analysis, EV excludes making allowances for variations necessary in compensating for unfavourable cases, thereby concealing much information.

Consider Fig. 7.15. Ventures A and B have the same EV outcome of $100 million. Venture A looks better as about 90 % of the time, the outcome will fall within a narrow range close to the EV. The chance of making a value less than $90 million in this venture is less than 5 %. Venture B has about 25 % chance of making a value less than $90 million, which could understandably be of concern to an investor with constrained capital. Venture A would generally be preferred since it is clearly shown to be a less risky alternative. It is only in Monte Carlo simulation that such clarity can be shown—as seen from the output distribution of Fig. 7.15.

A Monte Carlo model randomly selects an independent variable to solve for a dependent variable. By repeating this process several thousand times, the Monte Carlo model creates a probability distribution function (PDF) for the variables (Hall 2007; Newendorp 1975). Akin to financial analysis, Monte Carlo analysis assumes that past results indicate future performance.

Secondly, the three-level estimates—low, medium and high—may only be good enough for some situations where the amount of risks and/or variations in rewards are small compared to operating capital. In a more complex decision problem, like the situation with climate change or carbon dioxide sequestration, it does not go far.

Finally, a complete probability outcome spectrum in Monte Carlo simulation is the result of the interaction of several factors broken out and, individually, estimated more accurately, and then recombined by simulation.

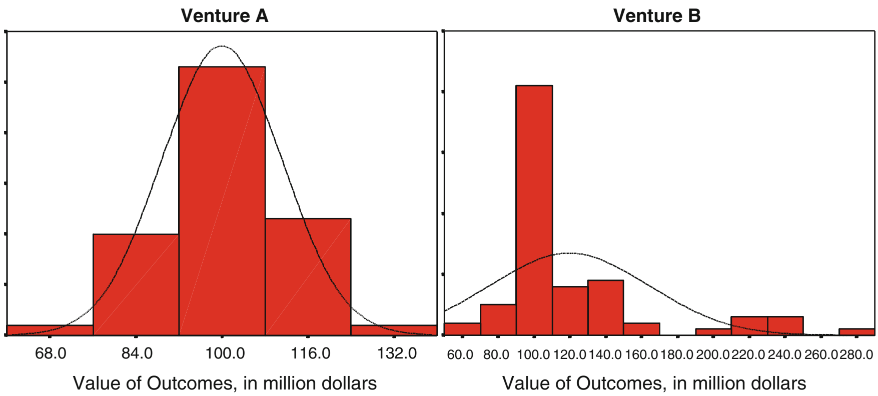


Fig. 7.15 Comparison of value outcomes of two environmental ventures

7.5 Concluding Remarks

This chapter sets the stage for the need to improve decision-making. The initial step in assessing risk is by modeling variability of future events and selecting investment options that avoid environmental disaster in bad times, and create opportunities in the good times. Every estimate, in every investment decision, contains errors. The real question is "how bad are the errors", "what is the impact of those errors?", and "can the project survive these forecasting errors?".

The strength of the risk assessment process depends to a large extent on a good understanding of the process being evaluated and the quality of information about an incident that has occurred, evaluation and interpretation of that information, and the identification of sound technical and feasible mitigation measures intended to lower risk. When assessing environmental risks, it is important that companies conduct a comprehensive assessment that addresses all aspects of the environment in which they operate, including air, water, land, natural resources, biodiversity, and communities.

The risk management approaches outlined in this chapter merely formalize and organize the informal analytical procedures operating under the tutelage of *experience* or *gut-feeling*. No methodology is perfect now or ever will be. In fact, if a perfect, easily understood methodology ever did exist, there would not be any need for such professionals such as risk and decision analysts. The merits of every analytical tool depend largely on the judgment of the professionals involved. Inputting bad values or misinterpreting the results defeats the fundamental objectives of risk and decision analysis, and, ultimately, may destroy the core purpose of the environmental risk assessment. Without understanding variability, good decisions are tough, if not impossible to achieve. Thus, variability is the key feature of environmental risk and decision analysis.

References

Beer T, Ziolkowski F (1995) Environmental risk assessment: an Australian perspective, being a supervising scientist report 102 presented at the 1995 Australian academy of science fenner conference on the environment, titled risk and uncertainty in environmental management, held in becker house, Canberra, 13–16 November

Borge D (2001) The book of risk. Wiley, New York

Cambell John M (2001) Analyzing and managing risky investments, 1st edn. John M. Campbell, Oklahoma

Clemen RT (1991) Making hard decisions. PWS-Kent Publishing Company, Boston

Damodaran A (2008) Strategic risk taking: a framework for risk management. Wharton School Publishing, Pearson Education, London, 390m p

Deel D, Mahajan K, Mahoney C, McIlvried H, Srivastava R (2007) Risk assessment and management for long-term storage of CO2 in geologic formations United States Department of Energy R&D. Syst Cybern Inform 5(1):7984

Edwards W (1997) How to use multiattribute utility theory for social decision making. IEEE Trans Syst Man Cybern 7:326–340

Gaus I (2010) Role and impact of CO2-rock interactions during CO2 storage in sedimentary rocks. Int J Greenh Gas Control 4:73–89
Hall RK (2007) Evaluating resource plays with statistical models. In: SPE hydrocarbon economics and evaluation symposium, Dallas, TX
Harding NR (2008) Application of stochastic prospect analysis for shale gas reservoirs. In: Paper presented at the 2008 SPE Russian oil and gas technical conference and exhibition held in Moscow, Russia, 28–30 October
Havranek TJ (1999) Modern project management techniques for the environmental remediation industry. CRC Press, Boca Raton, 456 p
Hesse MA, Orr FM, Tchelepi HA (2008) Gravity currents with residual trapping. J Fluid Mech 611:35–60
IPCC (2005) In: Metz B, Davidson O, Meyer L, de Coninck HC (eds) Intergovernmental panel on climate change (IPCC). Special report on carbon dioxide capture and storage. Cambridge University Press, Cambridge
Juanes R, Spiteri EJ, Orr FM Jr, Blunt MJ (2006) Impact of relative permeability hysteresis on geological CO_2 storage. Water Resour Res 42:W12418
Kahneman D, Tversky A (1979) Prospect theory: an analysis of decision under risk. Econometrica 47:263–291
Kamenetzky R (1982) The relationship between the analytic hierarchy process and the additive value function. Decis Sci 13:702–716
Kaplan S, Garrick B (1981) On the quantitative definition of risk. Risk Anal I:1–27
Kodukula P, Papudesu C (2006) Project valuation using real options: a practitioner's guide. J. Ross Publishing, Plantation, 256 p
Milosevic DZ (2003) Project management toolbox: tools and techniques for the practicing project manager. Wiley, New York, 584 p
Mun J (2012) Real options analysis: tools and techniques for valuing strategic investments and decisions, 2nd edn. Wiley, New York, 704 p
Newendorp P (1975) Decision analysis for petroleum exploration. Petroleum Publishing Co., Tulsa, p 187
Power M, McCarty LS (1998) A comparative analysis of environmental risk assessment/risk management frameworks. Environ Sci Technol 32(9):224A–231A
Riaz A, Hesse M, Tchelepi HA, Orr FM (2006) Onset of convection in a gravitationally unstable diffusive boundary layer in porous media. J Fluid Mech 548:87–111
Schuler John R (2001) Risk and decision analysis in projects. Project Management Institute, USA
Schulmerich M (2008) Real options valuation the importance of interest rate modelling in theory and practice, 2nd edn. Springer, Berlin, 389 p
Soong TT (2004) Fundamentals of Probability and Statistics for Engineers, John Wiley and Sons, 391 p
Standards Australia (2006) HB 203:2006: environmental risk management principles and process. SAI Global, Sydney
von Winterfelt D, Edwards W (1986) Decision analysis and behavioral research. Cambridge University Press, Cambridge, 604 p
Wakeman JB (2003) RE: decision analysis. In: Email to Igor Linkov, dated April 4, 2003. Includes attachment a: decision analysis based upon implementability of the action alternatives at Milltown Dam

Part III
Essential Tools and Techniques for Environmental Project Management

Chapter 8
Geospatial Tools and Techniques

A human being is part of a whole, called by us the universe, a part limited in time and space. He experiences himself, his thoughts and feelings, as something separated from the rest, a kind of optical delusion of his consciousness. This delusion is a kind of prison for us, restricting us to our personal desires and to affection for a few persons nearest us. Our task must be to free ourselves from this prison by widening our circles of compassion to embrace all living creatures and the whole of nature in its beauty.

—Albert Einstein (1879-1955)

8.1 Need for Geospatial Techniques in EnvPM

Throughout part III of the book, geospatial methods are used to provide analysis of project activities and their effect on the environment. Its use is informed by two main factors. First, environmental issues occur in space and as such are location or area-based, i.e., geographical in nature. Dasgupta et al. (2005) recommend that due to such spatial dimension of the environment, different environmental problems should be analyzed at different regional scales. They provide an example of pollution where they state (Dasgupta et al. 2005):

> *In the case of pollution, for example, the theoretically appropriate scale is affected by the dispersal characteristics of the pollutant and medium: Particulate pollution from cement mills may only be dangerous in one urban region; acid rain from sulfur emissions may damage forests hundreds of miles from the source; and eutrophication from fertilizer runoff may affect ocean fisheries a thousand miles downstream from the farms that are the source of the problem. In practice, data constraints often dictate the choice of the scale.*

Environmental degradation, e.g., from pollution as exemplified above by Dasgupta et al. (2005) can take on the local (e.g., from particulate air pollution, which results in cardiorespiratory health problems), regional, or/and global (e.g., global warming).

Second, administrative economics are spatial based. To this effect, Dasgupta et al. (2005) writes:

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Environmental Science and Engineering, DOI 10.1007/978-3-319-27651-9_8

On the environment side, for example, effective regulation requires local inspection of damage sources (pollution, deforestation, etc.), as well as more centralized facilities for information collection, storage, and analysis. Environmental management is undoubtedly improved by a knowledge of local conditions, but the marginal cost of administration rises with distance from administrative center, because of deteriorating transport and communications quality. Generally, province- or district-level administration strikes the right balance between headquarters scale economies and the cost of dispersed monitoring and enforcement operations.

Analysis of environmental pollution issues, therefore, needs to be spatially undertaken. This is because they occur in geographical space on the one hand, and from policy perspective, the environmental pollution is relevant only if it has implications for the allocation and administration of public resources for alleviation of environmental problems on the other hand. Geospatial techniques, e.g., remote sensing, geographical information system (GIS), or Gravity Recovery and Climate Experiment (GRACE) satellites mission discussed in subsequent chapters of this book provide innovative solutions to environmental degradation.

In what follows, basics of geospatial, starting with the concept of space is presented in Sect. 8.2. Geodata, the basic elements of geospatial are then presented in Sect. 8.3 followed by the new paradigm of the digital Earth in Sect. 8.4. Section 8.5 then gives the fundamentals of geospatial necessary for the reader to understand its applications in part III of the book.

8.2 Dimensions of Space, Time, and Scale

Understanding the characteristics of and possibilities in using geodata is premised on proper comprehension of the underlying concepts of space, time and scale, contextualized within the Earth's framework. Although these concepts are used in everyday parlance, often without much afterthought, they are not trivial at all. For instance, looking back throughout the entire history of mankind, the concepts of space and time have been the subject of animated philosophical, religious, and scientific debates. In this section, we attempt to present a background of each of these dimensions of geodata, both independently and collectively, as well as highlight their relevance in influencing the character of geodata.

Space is that boundless, three-dimensional extent in which objects and events occur and have relative position and direction (Britannica 2014). In analytical geometry, one examines "spaces" with different dimensionality and underlying structures. Indeed, the concept of space is considered to be of fundamental importance to an understanding of the physical universe although disagreement continues between philosophers over whether it is in itself an entity, a relationship between entities, or part of a conceptual framework (Wikipedia 2014).

Philosophical debates on the nature, essence and the mode of existence of space date back to antiquity. From treatises like that championed by *Timaeus of Plato* in his reflections on what the Greeks called *khora* (i.e., space), to the physics of *Aristotle* in the definition of *topos* (i.e., place), or to even the geometrical conception of place as *"space qua extension"* by *Alhazen* (El-Bizri 2007).

Many of the classical philosophical assertions were later discussed and reformulated in the 17th century, particularly during the early development of classical mechanics. For example, in *Sir Isaac Newton's* view, space was absolute, in the sense that it existed permanently and independent of whether there were any matter in the space (French and Ebison 2007). However, other philosophers like *Gottfried Leibnitz* were of the different view that space was a collection of relations between objects, given by their distance and direction from one another (Wikipedia 2014).

Up until around the 18th century, and within the framework of *Euclidean geometry*, space was perceived by most mathematicians to be flat. However, between the 19th and 20th centuries mathematicians began to examine *non-Euclidean geometries*, in which space was inferred to be curved, rather than flat. According to *Albert Einstein's* theory of general *relativity*, space around gravitational fields deviates from Euclidean space (Carnap 1995). Furthermore, experimental tests of general relativity have confirmed that non-Euclidean space provides a better model for the shape of space as illustrated in Fig. 8.1.

Turning to the dimension of time, time is considered to be part of the measuring system used to sequence events, to compare the durations of events and the intervals between them, and to quantify rates of change such as the motions of objects (Internet Encyclopedia of Philosophy 2014). This is the essence of managing all projects, particularly, environmental projects. The temporal position of events with respect to the transitory present is continually changing. It is a limited non-recyclable commodity. For example, future events become present, then pass further back into the past.

In the *Bible*, time is traditionally regarded as a medium for the passage of predestined events. Subsequently, there is an appointed time for everything, see e.g., *Ecclesiastes 3:1–8* (Bible 2014). Evidently, time has been a major subject in religion, philosophy, and science, but defining it in a non-controversial manner applicable to all fields of study has consistently eluded the greatest scholars (Wikipedia 2014).

Time is one of the seven fundamental physical quantities defined in the International System of (SI) Units. It is also used to define other quantities, such as velocity.

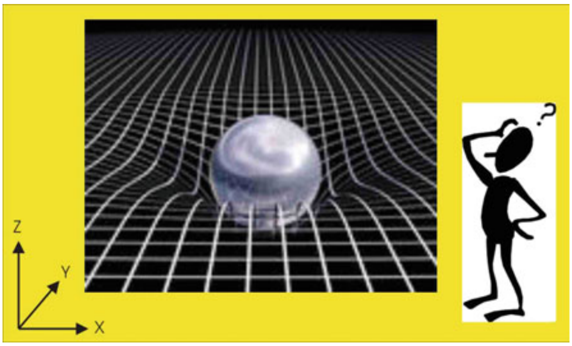

Fig. 8.1 Concept of non-Euclidean space

Time is the essence of managing all projects. It can also be defined as a limited, non-recyclable commodity (Badiru 2012).

An operational definition of time infers that observing a certain number of repetitions of one or another standard cyclical event (such as the passage of a free-swinging pendulum) constitutes one standard unit such as the second. This view is highly useful in the conduct of both advanced experiments and everyday affairs of life. However, this operational definition ignores the question whether there is something called *time*, apart from the counting activity that transits and can be measured (Wikipedia 2014).

Two contrasting assertions on time divide many prominent philosophers. The first view is that time is part of the fundamental structure of the universe, a dimension in which events occur in sequence. *Sir Isaac Newton* subscribed to this realistic view, and hence it is sometimes referred to as *Newtonian time*, see e.g., Rynasiewicza (1995a, b), Markosian (2002), etc. According to this view, time travel becomes a possibility as other "times" persist like frames of a film strip, spread out across the time line.

The second and opposing view contends that time does not refer to any kind of "container" that events and objects "move through", nor to any entity that "flows", but that it is instead part of a fundamental intellectual structure (together with space and number) within which humans sequence and compare events. This assertion, in the tradition of *Gottfried Leibnitz* (Burnham 2006) and *Immanuel Kant* (see e.g., Mattey 1997; McCormick 2006, etc.) holds that time is neither an event nor a thing, and thus it is not itself measurable nor can it be traveled.

Temporal measurement has occupied the minds of scientists for a long time and was the prime motivation in the disciplines of navigation and astronomy. Periodic events and periodic motion have long served as standards for units of time. Examples include the apparent motion of the sun across the sky, the phases of the moon, the swing of a pendulum, and the beat of a heart. Currently, the international unit of time, the *second*, is defined in terms of radiation emitted by cesium atoms. Time is also of significant social importance and is often viewed as having economic value as captured by the popular adage *time is money* or *time value of money*, as well as personal value, due to an awareness of the limited and finite time in each day and in the human life span (Wikipedia 2014). Consequently, different time scales are employed in different application domains, such as geological time (Haq 2006; Harland et al. 1989; Kulp 1961), biological time (Enright 1965; Hochachka and Guppy 1987; Winfree 2001), project time scheduling (Vanhoucke 2012), etc.

From the above discussion, regardless of the school of thought advanced, it is evident that historically, the dimensions of space and time have been closely related. As a matter of fact, it is virtually impossible to describe either of the two dimensions without inferring the other. Put together, these two dimensions represent the *space-time* concept expressed in Einstein's special relativity and general relativity theories. According to these theories, the concept of time depends on the spatial reference frame of the observer, and the human perception as well as the measurement by instruments such as clocks are different for observers in relative motion. Subsequently, the past is the set of events that can send light signals to the observer, whilst the future is the set of events to which the observer can send light signals (Wikipedia 2014).

This then brings us to the dimension of scale. The scale of a map is an important metric that defines the level of detail of geoinformation that can be extracted from such a map. Scale also gives an indication of the resolution in the geodata. In general, a larger scale means that more geodata would be captured, including fuzzy detail that might otherwise be generalized or glossed over at smaller scales. The interpretation of scale is therefore important. For instance, by simply varying the map scale alone, the estimated distance between two points would vary. Many researchers have studied the scale dimension and its perception and meaning in different applications, see e.g., Mandelbrot (1967), Fisher et al. (2004), Levin (1992), Tate and Wood (2001), etc. A review of space, time and scale from a geographer's perspective is given in Meentemeyer (1989).

For many years, the dimension of scale was not explicitly integrated into data modeling. Therefore, scale was assumed to be uniform within a spatio-temporal context. This was done ostensibly to keep the whole geo-modeling problem simplified. The fact that classical maps could only be produced at one specific scale probably reiterates this. By convention, national mapping agencies had to designate certain mapping scales for different map coverages. This therefore enabled map users to identify the maps that were suitable for different applications. For example, in typical engineering project management, whereas a scale of 1:50,000 would be appropriate at the reconnaissance or conceptual phase, larger scales of 1:500–1:2,000 would be required at the execution and/or maintenance phases.

Evidently, the scale dimension has not evoked as much controversy as the twin dimensions of space and time. The issue with the scale dimension has been more to do with the scientific challenge of identifying appropriate data models and structures. Indeed, consideration of scale as an extra dimension of geographic information, fully integrated with the other dimensions, is a fairly recent proposition (Oosterom and Stoter 2010). Whereas 3D space captures the geometrical characteristics of geodata, 4D integrates the temporal representation, with the 5D providing the scale definition. Meentemeyer (1989) avers that most geographic research is now conducted with a relativistic view of space rather than a view of space as a "container". However, spatial scales for relative space are more difficult to define than those for the absolute space of cartography and remote sensing (MeenteMeyer 1989).

In concluding this section, it is important to recognize that the five dimensions of space (X, Y, Z), time (t), and scale (S) are integral to the unambiguous definition of position for they help to fully integrate 5D data modeling. Realizing this would ensure that geodata is used seamlessly with no undesirable overlaps or gaps and assuming consistency across space, time and scale dimensions. In future, probably the existence and relative importance of different classes in diverse applications could also be considered in a more integrated manner as the sixth dimension of geodata—the *semantic* dimension (Oosterom and Stoter 2010).

8.3 Geodata

Data is simply defined as any set of raw facts or figures that have been collected, often in a systematic manner, and from which inference(s) may be drawn. Similarly, *information* is defined as any useful data that satisfies some user need(s). This is generally required to support the making of decisions. Apparently, data and information constitute the basic building blocks in the decision-making support infrastructure that also includes *evidence*, *knowledge*, and *wisdom* as summarized in Table 8.1.

An *information system* is a combination of technical and human resources, together with a set of organizing procedures that produces information in support of decision-making usually to meet some managerial requirement. Thus an information system should be able to receive, store, process, update, output and distribute data and information. Classical information systems for general management are called *Management Information Systems* (MIS). They are distinguished from *Geographic Information Systems*, which are information systems that deal with spatially referenced data.

Data is distinguished as *geodata* (or *geospatial* data) if it can be geographically referenced in some consistent manner using for example; latitudes and longitudes, national coordinate grids, postal codes, electoral or administrative areas, watershed basins, etc. As mentioned in Sect. 8.2, although geodata is normally defined in 3D in many practical applications, it needs to be redefined in 5D for geodata to be used without any restrictions in space, time or scale. The first three dimensions describe the geometric characteristics of geodata usually in 3D space. The fourth dimension provides the temporal representation that denotes how geodata has changed over time, while the scale is represented by the fifth dimension. This dimensional view

Table 8.1 Hierarchy of decision making support infrastructure (Modified after Longley et al. 2005)

Level of decision-making support infrastructure	Ease of sharing	Example
Wisdom ⇑	Impossible	Policies developed and accepted by stakeholders e.g., ideal use for parcel
Knowledge ⇑	Difficult (especially tacit knowledge)	Personal knowledge about places and issues e.g., adjoining parcel boundaries
Evidence ⇑	Often not easy	Results of spatial analysis of datasets or scenarios e.g., parcel area
Information ⇑	Easy	Contents of a database assembled from raw facts e.g., owner of parcel
Data	Easy	Raw facts and figures e.g., geographic coordinates

of geodata is important for it ensures that there are no gaps or overlaps in the data. Furthermore, it also maintains the consistency of geodata across space, time and scale dimensions.

Geodata may be collected by both government organizations as well as private agencies. A key characteristic of this type of data is its potential for diverse and multiple applications. Moreover, geodata can be shared and re-used by different users and applications through the *spatial data infrastructure* (SDI), see e.g., Groot and McLaughlin (2000), SDI Cookbook (2004), Maguire and Longley (2005)), etc. To infer the correct decision(s), it is imperative that the geodata be *accurate, complete, consistent,* and *timely*. Furthermore, it is important that the required geodata be made available and that in addition, it also be allowed to flow unhindered to and between the various users and applications.

8.4 Digital Earth Concept

Digital Earth is the name given to a concept coined by former US vice president Al Gore in 1998, that describes a virtual representation of the Earth that is spatially referenced and interconnected with the world's digital knowledge archives.[1] Furthermore, the greater part of this knowledge store would be free to all via the *Internet*. However, a commercial marketplace of related products and services was envisioned to co-exist, in part in order to support the expensive infrastructure that such a system would require (Wikipedia 2014).

Clearly, many aspects of this vision have been realized, evidenced in part by the popularity of virtual globe geo-browsers such as *Google Earth*[2] for commercial, social, and scientific applications. But the Gore speech outlined a truly global, collaborative linking of systems that has yet to be fully realized (Wikipedia 2014). That vision has been continually interpreted and refined by the growing global community of interest. As technological advances have made the unlikely possible, the vision has evolved and become more concrete, and as we better understand the interdependence of the environment and social activities, there is greater recognition of the need for such a system. Digital Earth has come to stand for the large and growing set of web-based geographic computing systems worldwide. These are both useful and promising, but do not yet constitute the envisioned *global commons* (Wikipedia 2014).

[1]In a speech prepared for the California Science Center in Los Angeles on January 31, 1998, Gore described a digital future where school children—indeed all the world's citizens—could interact with a computer-generated three-dimensional spinning virtual globe and access vast amounts of scientific and cultural information to help them understand the Earth and its human activities.

[2]http://www.earth.google.com.

The global dimension of the digital Earth concept is perhaps best captured by two excerpts from the Beijing declaration[3] on digital Earth, which state as follows (Beijing 2009):

(a) Digital Earth is an integral part of other advanced technologies including: Earth observation, geo-information systems, global positioning systems, communication networks, sensor webs, electromagnetic identifiers, virtual reality, grid computation, etc. It is seen as a global strategic contributor to scientific and technological developments, and will be a catalyst in finding solutions to international scientific and societal issues;
(b) Digital Earth should play a strategic and sustainable role in addressing such challenges to human society as *natural resource depletion*, *food and water insecurity*, *energy shortages*, *environmental degradation*, *natural disasters response*, *population explosion*, and, in particular, *global climate change*.

A consortium of international geographic and environmental scientists from government, industry, and academia brought together by the *Vespucci Initiative for the Advancement of Geographic Information Science, and the Joint Research Center of the European Commission* published a position paper that outlined the eight key next generation Digital Earth elements to include the following (Craglia et al. 2008):

(1) Not one Digital Earth, but multiple connected globes/infrastructures addressing the needs of different audiences: citizens, communities, policy-makers, scientists, educationalists;
(2) Problem oriented: e.g., environment, health, societal benefit areas, and transparent on the impacts of technologies on the environment;
(3) Allowing search through time and space to find similar/analogous situations with real time data from both sensors and humans (different from what existing GIS can do, and different from adding analytical functions to a virtual globe);
(4) Asking questions about change, identification of anomalies in space in both human and environmental domains (flag things that are not consistent with their surroundings in real time);
(5) Enabling access to data, information, services, and models as well as scenarios and forecasts: from simple queries to complex analyses across the environmental and social domains;
(6) Supporting the visualization of abstract concepts and data types (e.g., low income, poor health, and semantics);
(7) Based on open access, and participation across multiple technological platforms, and media (e.g., text, voice and multi-media); and
(8) Engaging, interactive, exploratory, and a laboratory for learning and for multidisciplinary education and science.

[3]Ratified on September 12, 2009 at the 6th international symposium on digital earth in Beijing, Peoples Republic of China.

8.5 Fundamentals of Geospatial

Having introduced the 5D datum paradigm that needs to be adequately dealt with to define geodata accurately, consistently, timely and completely so that it can be used without any restrictions in space, time or scale and further, having appreciated the truly global dimension of the digital Earth, to put everything in perspective, it is now appropriate to focus on geospatial.

The bottom line is that there is no globally accepted definition of geospatial. As a multidisciplinary field, geospatial has at its core different technologies that support the acquisition, analysis, and visualization of geodata. The geodata is usually acquired from Earth observation sensors as remotely sensed images, analyzed by geographic information systems (GIS) and visualized on paper or on computer screens. Furthermore, it combines geospatial analysis and modeling, development of geospatial databases, information systems design, human-computer interaction and both wired and wireless networking technologies. Geospatial uses geocomputation and geovisualization for analyzing geoinformation. Typical branches of geospatial include: *cartography, geodesy, geographic information systems, global navigation satellite systems (GNSS), photogrammetry, remote sensing, and web mapping*.

By combining the ever-increasing computational power, modern telecommunications technologies, abundant and diverse geodata, and more advanced image analysis algorithms available, and integrating technologies such as remote sensing, GIS and GNSS, many opportunities for application of geospatial have been realized. Today, many applications routinely benefit from geospatial including; urban planning and land use management, in-car navigation systems, virtual globes, public health, local and national gazetteer management, environmental modeling and analysis, military, transport network planning and management, agriculture, meteorology and climate change, oceanography and coupled ocean and atmosphere modeling, business location planning, architecture and archaeological reconstruction, telecommunications, criminology and crime simulation, aviation and maritime transport, etc.

Consequently, geospatial has become a very important technology to decision-makers across a wide range of disciplines, industries, commercial sector, environmental agencies, local and national government, research and academia, national survey and mapping organizations, international organizations, United Nations, emergency services, public health and epidemiology, crime mapping, transportation and infrastructure, information technology industries, GIS consulting firms, environmental management agencies, tourist industry, utility companies, market analysis and e-commerce, mineral exploration, etc. Increasingly, many government and non government agencies worldwide are using geodata and geospatial for managing their day to day activities. Figure 8.2 shows a conceptual framework that underlines the role of geospatial in supporting the environmental project management framework developed in Chap. 5.

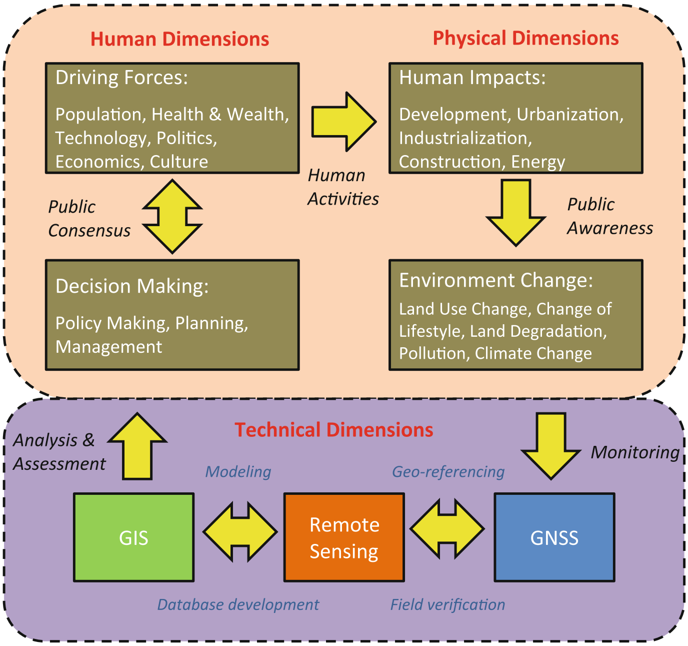

Fig. 8.2 Conceptual framework showing the role of geospatial in environmental project management (Modified after Murai 1999)

8.6 Concluding Remarks

Although still unusual in many practical mapping constructs worldwide, a 5D coordinate reference framework is, nonetheless, desirable. This would not only ensure that geodata are defined accurately, consistently, timely and completely, but also guarantee that they are employed without any restrictions whatsoever in terms of space, time and/or scale. There is no doubt that, perhaps more that ever before, humanity faces a myriad of complex and demanding challenges today. These include natural resource depletion, food and water insecurity, energy shortages, environmental degradation, intermittent natural disasters, population explosion, global climate change, etc. To develop pragmatic and sustainable solutions to address these and many other similar challenges requires the use of geodata and the application of geospatial tools.

References

Badiru AB (2012) Project management: systems. Taylor and Francis Group, CRC Press, Boca Raton, Principles and applications

Beijing (2009) In: Proceedings of the 6th international symposium on digital earth (ISDE6), Beijing, 9–12 Sept 2009

Bible (2014) King james version. www.kingjamesbibleonline.org. Accessed 4 May 2014

Britannica (2014) http://www.britannica.com/. Accessed 30 Mar 2014

Burnham D (2006) Gottfried Wilhelm Leibniz (16461716) metaphysics 7. Space, time, and indiscernibles. The internet encyclopedia of philosophy

Carnap R (1995) An introduction to the philosophy of science. Courier Dover Publications, New York, p 300

Craglia M, Goodchild MF, Annoni A, Camara G, Gould M, Kuhn W, Mark D, Masser I, Maguire D, Liang S, Parsons E (2008) Next-generation digital earth. Int J Spat Data Infrastruct Res 3:146–167

Dasgupta S, Deichmann U, Meisner C, Wheeler D (2005) Where is the poverty environment nexus? Evidence from Cambodia, Lao PDR, and Vietnam. World Dev 33(4):617–638. doi:10.1016/j.worlddev.2004.10.003

Enright, (1965) The search for rhythmicity in biological time-series. J Theor Biol 8(3):426–468

Fisher P, Wood J, Cheng (2004) Where is Helvellyn? fuzziness of multi-scale landscape morphometry. Trans Inst B Geogr 29:106–128

French AP, Ebison M (2007) Introduction to classical mechanics. Chapman and Hall, London, p 341

Groot R, McLaughlin J (eds) (2000) Geospatial data infrastructure: concepts cases and good practice. Oxford University Press, Oxford

Haq BU (2006) The geological time table Wallchart, 6th edn. Elsevier, New York

Harland WB, Armstrong RL, Craig LE, Smith AG, Smith DG (1989) A geologic time scale. Cambridge University Press, Cambridge

Hochachka PW, Guppy M (1987) Metabolic arrest and the control of biological time. ISBN 0-674-56976-8

Internet Encyclopedia of Philosophy (2014) http://www.iep.utm.edu/. Accessed 13 Mar 2014

Kulp JL (1961) Geologic time scale. Science 133(3459):1105–1114. doi:10.1126/science.133.3459.1105

Levin SA (1992) The problem of pattern and scale in ecology. Ecology 73

Longley PA, Goodchild MF, Maguire DJ, Rhind DW (2005) Geographic Information systems and science. John Wiley, New York

Maguire DJ, Longley PA (2005) The emergence of geoportals and their role in spatial data infrastructures. Comput Environ Urban Syst 29(1):3–14

Mandelbrot B (1967) How long is the coast of Britain? statistical self-similarity and fractional dimension. Science. New Series 156(3775): 636–638

Markosian N (2002) Time. In: Zalta EN (ed) The stanford encyclopedia of philosophy

Mattey GJ (1997) Critique of pure reason, Lecture notes: philosophy 175. University of California, Davis

McCormick M (2006) Immanuel kant (17241804) metaphysics: 4. Kant's transcendental idealism, The Internet encyclopedia of philosophy

MeenteMeyer V (1989) Geographical perspectives of space, time, and scale. Landsc Ecol 3(3–4):163–173. doi:10.1007/BF00131535 (Springer)

Murai S (1999) GIS work book: fundamental and technical courses. National Space Development Agency of Japan (NASDA)/Remote Sensing Technology Center of Japan (RESTEC), vols 1–2. Japan Association of surveyors

Nader El-Bizri (2007) In defence of the sovereignty of philosophy: al-Baghdadi's critique of Ibn al-Haytham's geometrisation of place. Arab sci philosoph Hist J. Cambridge University Press 17:57–80

Oosterom P, Stoter J (2010) 5D data modelling: full integration of 2D/3D space, Time and scale dimensions. In: Fabrikant SI et al. (ed) GIScience 2010, LNCS 6292, Springer, Berlin, p 310324

Rynasiewicza R (1995a) By their properties, causes and effects: newton's scholium on time, space, place and motion. Part I: the text. Stud Hist Philosoph Sci 26:133–153

Rynasiewicza R (1995b) By their properties, causes and effects: newton's scholium on time, space, place and motion. Part II: the context. Stud History Philosoph Sci 26:295–321

SDI Cookbook (2004) Developing spatial data infrastructures: the SDI cookbook, Global spatial data infrastructure, In: Nebert DD (ed), Technical working group chair, GSDI
Tate N, Wood J (2001) Fractals and scale dependencies in topography. In: Tate N, Atkinson P (eds) Modelling scale in geographical information science, Wiley, New York, p 3551
Vanhoucke M (2012) Project management with dynamic scheduling: baseline scheduling, risk analysis and project control, vol XVIII. Springer, Berlin
Wikipedia (2014) http://en.wikipedia.org/wiki/. Accessed 28 Mar 2014
Winfree AT (2001) The geometry of biological time, Springer, Berlin, p 777 [ISBN 0387989927]

Chapter 9
Global Navigation Satellite System (GNSS)

Any measurement must take into account the position of the observer. There is no such thing as measurement absolute, there is only measurement relative. Jeanette Winterson. In that case, Measure what is measurable, and make measurable what is not so

—Galileo Galilei (1564–1642)

9.1 Environmental Monitoring Parameters

In this section, we discuss the *quantitative* and *qualitative data* that could be collected using GNSS satellites, and in so doing, attempt to answer the question "what can GNSS satellites deliver that is of use to environmental monitoring?" The observed parameters necessary for environmental monitoring vary, depending upon the indicators being assessed. Some are *physical variables* such as changes in soil patterns, vegetation, rainfall, water levels, temperature, deforestation, solar and UV radiation. Others are *chemical variables*, e.g., pH, salinity, nutrients, metals, pesticides, while others are *biological variables*, e.g., species types, ecosystem health, and indicator species.

GNSS satellites are useful in measuring physical variables such as atmospheric temperature, pressure, and tropopause heights needed for weather and climate change monitoring, see e.g., Awange (2012). For chemical and biological variables, the main environmental monitoring parameter provided by these satellites is the *position* of the respective variable. Positions are useful not only in providing physical locations, but also in measuring spatial variation in the variables being monitored.

For example, monitoring coastal erosion can be undertaken by the constant monitoring of shoreline positions using GNSS satellites as shown by Goncalves (2010), Goncalves et al. (2012). In other environmental monitoring examples, satellite derived positions could complement other systems to enhance monitoring. For example, global navigation satellite systems (GNSS) satellites complement low-flying satellites such as the Gravity Recovery And Climate Experiment (GRACE) to allow more detailed and accurate monitoring of mass redistribution on the Earth's

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surface. Such mass distribution include, e.g., variations in surface and groundwater at local, regional and global scales as discussed in Awange (2012). For dynamic environmental phenomena, such as variations in deforestation, GNSS satellites could provide efficient tools for measuring such changes by providing time series of their variation in position.

A large number of global GNSS instruments, such as the ones discussed in this chapter were used to record geographic coordinates and the points from which samples of pollution on Ogoniland, River State of Nigeria were collected. The GNSS was also used to map the road network of Ogoniland and accessibility for the purpose of planning daily transportation to and from sampling sites (see Sect. 19.1.3.3), p. 391.

9.2 Design of GNSS Monitoring Survey

In order to achieve maximum benefit from the use of GNSS satellites for environmental monitoring, it is essential that proper measurement procedures be undertaken with clear aims, and objectives. As in all measurements, the quality of the observations will be determined by the purpose and objectives and, to a greater extent, the client's requirements. These objectives and needs will dictate the methods chosen for *data collection*, the *frequency of data collection*, and *temporal* and *spatial* extent. The monitoring design should therefore specify the monitoring variables desired from GNSS satellites, where, when and by whom the data shall be collected. Like other environmental monitoring techniques, GNSS satellite monitoring also requires some *baseline survey* or information upon which any change in the environment could be referred to. In the case of positions, permanent reference stations whose locations are accurately known normally provide such references. Any spatial change (i.e., change in the environmental variable being monitored with regards to position) will then be referred to these points. Measurements can be repeatedly taken at given time intervals (temporal resolution) depending on the monitoring budget and the desired accuracy.

The final accuracy of the collected data will depend on how the errors are handled. For GNSS satellite monitoring, these errors (see Awange 2012) could be external (i.e., outside the user's control) or internal (i.e., during the actual measurements). In this chapter, GNSS measurement procedures that may help minimize errors and achieve meaningful results relevant for environmental monitoring are presented.

GNSS surveys can be divided into three components:

- *Planning and reconnaissance*: This is an essential part of any monitoring campaign. For a GNSS survey, it is essential to plan the measuring campaign in such a manner that the errors are minimized. For example, it is important that the sky visibility and satellite paths are plotted in a skyplot for the survey area and the desired survey period. The advantage of having sky plots is that the number of satellite visible during the planned observation period and features blocking the satellite are determined in advance. The main objective is to ensure unobstructed view of at least four satellites with a good geometric distribution in the sky. Satellite geometry is indicated by the dilution of precision (DOP) factor. Reconnaissance provides the opportunity of visiting the survey site prior to the actual GNSS survey and assessing the availability of existing reference stations (geodetic control) and accessibility to these stations, while at the same time looking out for potential sources of errors such as buildings and trees that can cause multipath errors. The advantage of undertaking reconnaissance and planning prior to a satellite survey is that it can significantly reduce some logistical problems such as setting up a receiver in an area where the signals would be blocked.

- *Undertaking the monitoring survey*: Once the aims and objectives of the environmental monitoring project have been identified and the reconnaissance done, the survey task can be executed through proper *choice of GNSS positioning method*, *undertaking care in the actual survey procedures*, and *avoiding or minimizing errors where possible* (e.g., setting the receiver in an open space that is not very close to buildings to reduce the likelihood of multipath errors).
- *Processing of the data*: In order to obtain the monitoring parameters or baseline information from the GNSS observation, data can be processed in real-time or during post-processing.

9.3 Mission Planning and Reconnaissance

Satellite signals are measurable quantities that are needed to generate monitoring information. GNSS signals are microwaves (see Chap. 11) that penetrate cloud cover and travel under all weather conditions, but unfortunately cannot penetrate dense *vegetation* canopies or buildings. Because of this, and in order to reduce the detrimental effects of atmospheric refraction and multipath signals, it is desirable that the antenna has as clear view of the sky as possible. An elevation angle of above 15° is often considered suitable to enable a clear sky view, although this could at times be as low as 10°. Some antennas are equipped with a ground plane that blocks unwanted multipath signals from reaching the antenna.

Nearby metallic objects, such as fences and power lines, should be avoided where possible in order to prevent imaging, i.e., when metallic objects act as secondary antennas, thereby distorting the positions derived from GNSS satellites. It is therefore recommended that the GNSS observation sites be selected in open areas away from potential sources of multipath and imaging where possible.

As already pointed out, the geometrical strength of the satellite constellations will contribute to the quality (accuracy) of the positions obtained. A weaker geometry from satellites close together in the sky as illustrated in Fig. 9.1 (right) will contribute to geometrically weaker solutions while solutions computed by observing satellites evenly distributed in the sky (e.g., Fig. 9.1, left) will lead to geometrically stronger solutions. Both geometric dilution of precision (GDOP) and position dilution of precision (PDOP) are useful in measuring the geometrical strength of a satellite constellation, but PDOP is the most commonly used. PDOP is computed from the

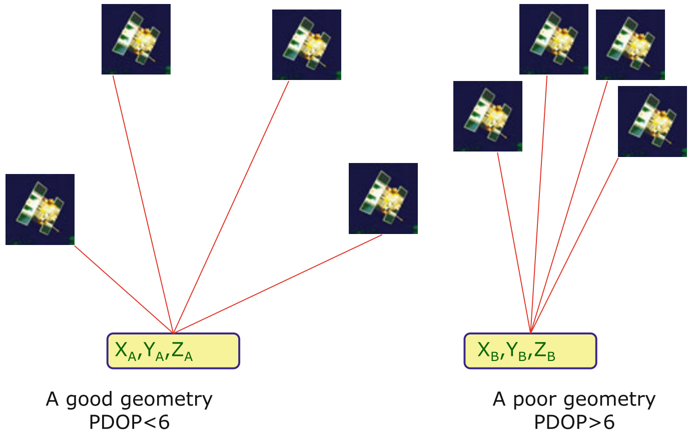

Fig. 9.1 Satellite geometry: *Left* (good geometry); *Right* (poor geometry)

positions of the satellites in relation to the receiver and takes a single value, see e.g., Hofman-Wellenhof et al. (2008, pp. 262–266). It is a measure based solely on the geometry of the satellites and therefore can be computed prior to any observation being taken. A higher PDOP value (i.e., >6) indicates a poor satellite geometry for computing a position. In mission planning therefore, PDOP values are computed and used to indicate the observation window where the satellite constellation is adequate.

Satellite geometry becomes more crucial when one is observing over short occupation times, as is often the case in real-time kinematic (RTK) surveys discussed in Sect. 9.4.6. Whereas satellite geometry can be improved by longer observation period, poor sky visibility combined with a low number of satellites above the horizon can severely compromise static solutions.

This essentially means that before a successful GNSS environmental monitoring campaign is undertaken, it is essential to know when bad situations are likely to occur so that they can either be avoided or the survey team prepare itself for a significantly longer period of observation. This knowledge can only be made possible through careful reconnaissance and well executed *mission planning*. Mission planning is thus a very vital component of any GNSS environmental monitoring campaign.

If the only possible observation window gives a PDOP between 6 and 10, it is recommended that the observation time frame be between 30–45 min. For PDOPs greater than 10, it might be necessary to postpone the observations. If, for whatever reason, postponing is not feasible, then the observation period should be made as long as possible, assuming of course that the effects of other errors such as multipath are minimal. If this is not possible, then it may not be possible to achieve as accurate position for this point using satellite positioning as one may wish, regardless of the length of the observation time.

Finally, a word of caution is necessary. PDOP values only indicate when satellites are likely to produce good or bad results and should therefore not be considered as a measure of the actual quality of the positions. Awange (2012) discusses the quality estimation during the post-processing of the satellite data.

The basic stages for planning a GNSS survey are generally as follows:

1. Locate unknown control points and update reference marks information if necessary.
2. Assess the suitability of unknown control points for GNSS positioning and check for multipath sources in the vicinity.
3. If necessary, construct a visibility diagram using a compass and a clinometer (see, e.g., Fig. 9.2). The compass will provide an approximate position from the true North, while the clinometer will give the elevation of features such as buildings and vegetation. This will indicate the satellites likely to be blocked by tall buildings and trees. Such a diagram should also contain information on potential multipath sources.
4. Locate local reference stations. This will provide baseline positioning information.
5. Assess the suitability of these reference stations for satellite surveying and check for multipath sources in the vicinity.

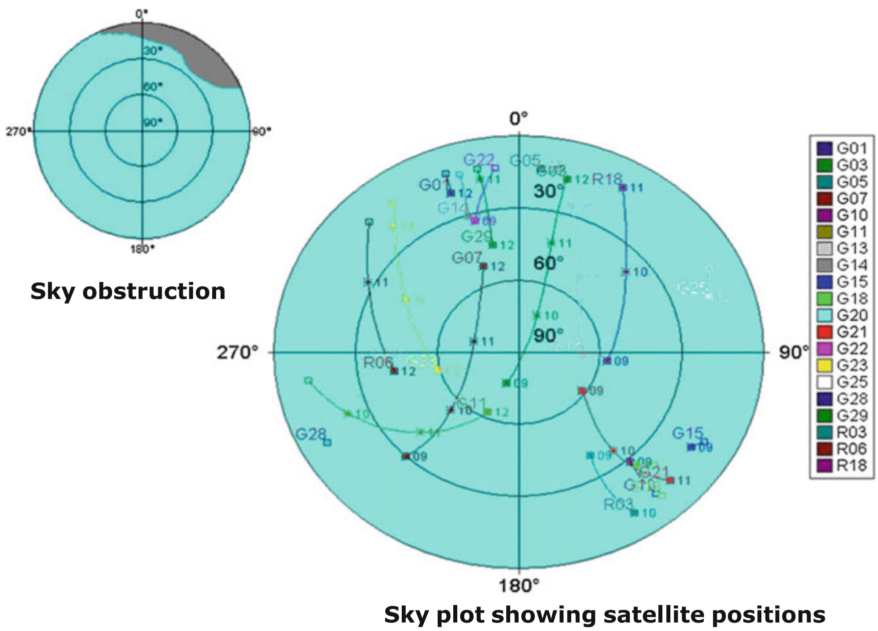

Fig. 9.2 Satellite visibility diagram of Astro deck 8 located at one of the buildings of the Curtin University (Australia) campus on the 16th of May 2008. *Left* Obstructed sky is noted at elevation 28° and azimuth between 0° to 60°. *Right* Satellite travel paths. The *colors* indicate the individual satellites

Example 9.1 (Mission planning)
In order to decide on the appropriate time to carry out GNSS observations, any mission planning software such as those of Sokkia or Trimble could be used. Most receivers will come with software, which are capable of conducting mission planning that can be used to indicate the position of the satellites during the desired observation time. The software provides DOPs, which are useful in indicating the geometrical strength of the satellite constellation as already discussed. The following example illustrates how mission planning can be undertaken using any available commercial software. In general, the operational steps of most mission planning software are similar and will tend to give similar results. Using any planning software, one would generally proceed as follows:

- *Step 1 (Running the software)*: Within the appropriate user window of the software, start by inserting the *dates* over which you wish to undertake the GNSS survey and the *approximate coordinates* of the point for which the receiver will be stationed during the selected day. Approximate coordinates of this station can be entered in terms of latitude and longitude since the satellite constellation varies slowly with distance. You may enter the latitudes and longitudes of your local area for example by selecting your city from an option list which is often provided.
- *Step 2 (Setting the time zone)*: It is convenient when planning the survey to work in local standard time, thus, ensure the time zone is correct.
- *Step 3 (Loading the almanac)*: The almanac contains information about the satellite positions in their orbits and are normally send as part of the navigation message. GPS receivers collect broadcast ephemerides, which are satellite positions broadcast to the receiver by the satellites themselves. For precise positioning, broadcast ephemeris are valid for a maximum of 4 h but are repeated every hour. However, mission planning can use these ephemerides to predict satellite orbits over a period of about a month. Note that the more recent the ephemeris, the more precise are the planning mission results. Most GNSS receivers automatically acquire almanac data during regular operations. One way of accessing the current almanac data is to carry out quick observations (e.g., about 15 min) without necessarily setting up the antenna to survey specifications. The almanac can also be obtained from the Internet.[1]
- *Step 4 (Planning graphs)*: Within the mission planning software, graphs giving various types of information for the day specified can be viewed. These graphs will indicate *satellite elevations plotted against time*, *satellite azimuths plotted against time*, *number of available satellites plotted against time*, representation of the *visibility time spans* of individual satellites, separate displays plotting the respective types of *dilution of precision (DOP) against time*, and *satellite tracks* through the time interval being plotted, showing elevations and azimuths in polar coordinates. Figure 9.3 presents an example of visibility time spans of individual satellites for station Astro deck 8 at Curtin University, Australia. A plot of the

[1]E.g., typing YUMA + GPS leads to http://celestrak.com/GPS/almanac/Yuma/.

number of visible satellites and the related DOP is given in Fig. 9.4. Together with the skyplot in Fig. 9.2, these four diagrams can be used to obtain an indication of the state of the satellite constellation during the period planned for the GNSS environmental monitoring survey.

For instance, looking at the skyplot Fig. 9.2 (left), one notices that the sky is blocked at an elevation of 28° and an azimuth between 0°–60°. The corresponding plot of satellite visibility (right) shows that this obstruction would most likely affect satellite R18. At this stage, the Planning software assumes a perfect satellite coverage, i.e., that no satellite is unhealthy and no obstructions exist above a given cutoff elevation angle (usually 15°). In reality, obstructions will exist at some sites and some satellites may be known to be malfunctioning. Therefore, the Planning software must be modified to give a more realistic situation. For example, if a satellite is known to have problems, the software would allow it to be excluded from the planning.

Figure 9.3 shows the visible satellite for a whole day while Fig. 9.4 present the corresponding DOP values. The greater the number of visible satellites and the better the geometry, the lower the DOP values. In this example, done for the 16th May 2008, it can be seen that the time between 11:00–11:20 had the least number of satellites and the corresponding DOP values were higher. The maximum DOP value in this example was 4, which meant that the satellite observations could be undertaken at anytime before 12:00. The period after 9:40 had more than 10 satellites in view and as can be seen, the corresponding values of DOP were lower. It should be pointed out, however, that in this example, both GPS and GLONASS satellites were used, hence the larger number of satellites and lower DOP.

♣ End of Example 9.1

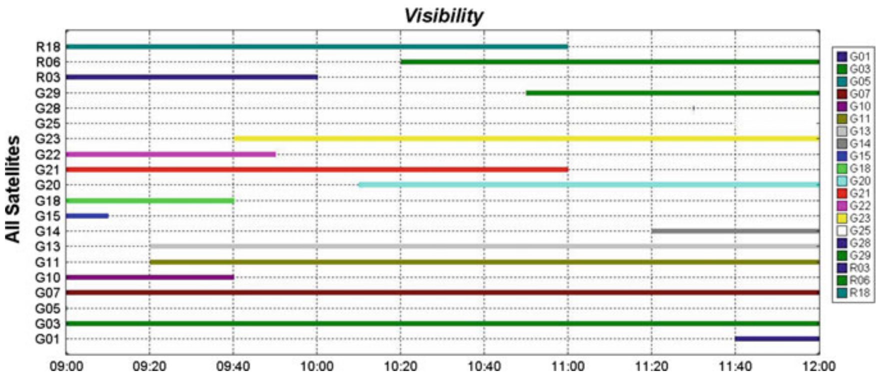

Fig. 9.3 Time spans of the visibility of individual satellites at Astro deck 8 of Curtin University, Australia

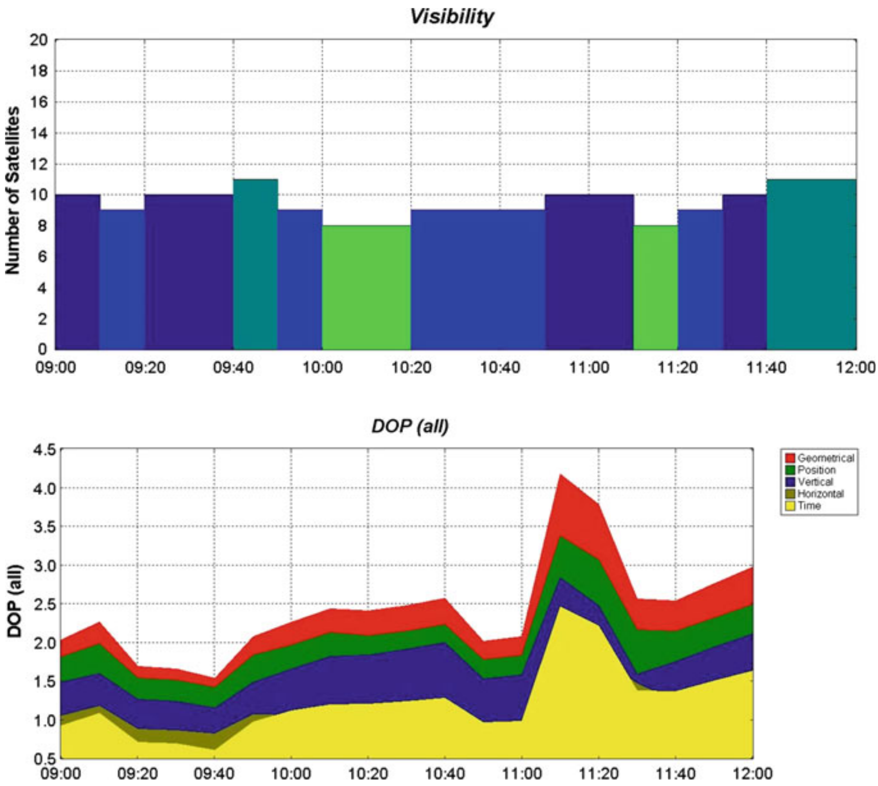

Fig. 9.4 Number of visible satellites (*top*) and the related DOP (*bottom*)

9.4 GNSS Field Procedures

Having done the planning, the next step involves the actual procedure for the field measurements. The objective of a given monitoring environmental task will dictate the types of equipment required. If the objectives call for more precise and accurate work, e.g., monitoring rise in sea level (see, e.g., Awange 2012), then the correct receivers and field procedure must be adopted. One of the tasks undertaken during a GNSS survey is the setting up of the antenna over some mark. These marks consist of pillars upon which the GNSS receiver is set (e.g., Fig. 9.5) or some marks on the ground, in which case a tripod has to be used (e.g., Fig. 9.6). In older GNSS equipment, the receivers and antennas were separate components but modern equipment such as Sokkia and Trimble incorporate both receivers and antennas in one unit.

Setting up the antenna over a mark should be done as accurately as possible in order to reduce centering errors. The receiver must be *leveled*, *aligned over each point*, and the *height of its geometrical center above the point recorded*. Antenna heights are normally measured to the phase center. Sometimes, this phase center does not

Fig. 9.5 Reference station, pillar 18 at Curtin University, Australia

Fig. 9.6 Setting up an antenna and measuring its height at Station John Walker (JW) at Curtin University, Australia

coincide with the geometrical center of the antenna leading to antenna phase center variation (e.g., Awange 2012). In high precision satellite measurements, this phase center variation can lead to errors in the range of millimeters to a centimeter. Most precise (geodetic) receivers posses antenna phase center models, which can reduce this effect during the post-processing of the measurements. In relative positioning (Sect. 9.4.2), the error due to phase center variation can be eliminated through the matching of the antennas by aligning both to North.

The most common source of error during the setting up of the antenna is the incorrect measurement of the antenna height. Since GNSS provides three-dimensional positions, any error in height determination will propagate to contaminate the lateral position, and vice versa. As a standard practice, comprehensive field notes should be kept, which should include the *station and surveyor's name*, *start and end times of the survey*, *type of receivers and antennae used*, *data file names*, *satellites used*, *details of reference marks*, *potential sources of errors and obstructions* and *most importantly, the antenna height*.

9.4.1 Single Point Positioning

Depending on the environmental monitoring task at hand, the single point positioning operation can take the form of *absolute point positioning*, also called autonomous positioning in some books, *relative positioning* or *differential positioning*. For absolute point positioning, known pseudoranges have to be measured to the satellites whose positions must be known. The accuracy of the positioned point will therefore rely on how well these ranges are measured and how good the satellite positions are known. It should be pointed out that repeated measurements leading to redundant observations will generally improve range accuracy (US Army Corps of Engineers 2007).

If the task just requires a simple location of a station, e.g., the location of a *soil analysis pit*, with an accuracy of several meters, then a low-cost, hand-held GNSS receiver will suffice. These kinds of receivers use *code pseudoranges* and are the ones commonly used for personal navigation in cars, boats, low-accuracy GIS data capture, etc. Hand-held receivers provide absolute positioning to a horizontal accuracy of about 5–15 m (95 % of the time). Decimeter accuracy can be achieved by stationing a receiver over a station of interest and taking observations for 30–45 min. Future modernized GNSS satellites are expected to improve the positioning accuracy by an order of magnitude (see Fig. 9.7). This improvement will come as a result of improved satellite orbit determination, improved receiver technology, additional user signal L2C, which would assist in modelling ionospheric errors, and additional ground monitoring stations.

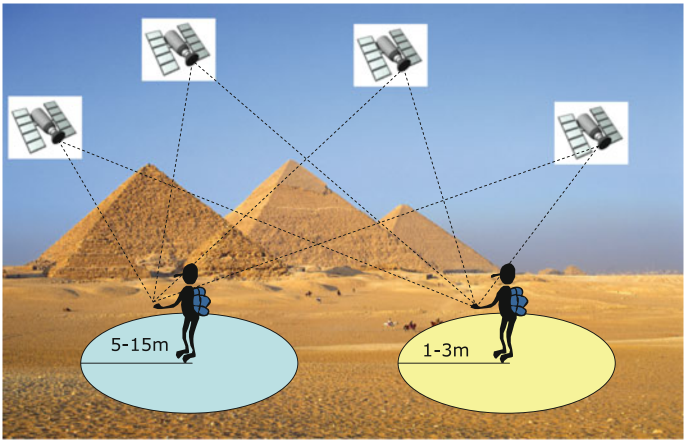

Fig. 9.7 Improved point positioning accuracy following modernization of GNSS satellites and receiver technology

9.4.2 Static Relative Positioning

Where a reference station (i.e., of known position) exists (e.g., Fig. 9.5), the static *relative positioning* method is recommended for higher positioning accuracy. In this mode of operation, *two GNSS receivers* or more are required in order to observe the same satellites simultaneously. Although additional cost is incurred in providing more equipment, the advantage over absolute point positioning is the capability of eliminating or minimizing errors associated with the atmosphere and satellite orbits through differencing techniques (see e.g., Awange 2012).

The method is more effective over short baselines of less than 20 km where the atmospheric errors are assumed to be the same. Using this method, one receiver will be set at a reference (control) station (Fig. 9.5) while the other receiver will be set at an unknown station (e.g., Fig. 9.6). Tracking of satellites must then be simultaneous and synchronized. The observation time would normally take 20 min to 1 h with data being sampled at intervals of 10–15 s. Longer durations of observation benefit from improved satellite geometry leading to better solution of the unknown integer ambiguities $\{N\}$. When the settings are properly done, and errors minimized through proper prior planning, the method is capable of giving coordinate differences $(\triangle X, \triangle Y, \triangle Z)$ to a centimeter to millimeter level accuracy. The method is useful in the establishment of higher precision control networks (baseline reference networks) useful for environmental monitoring.

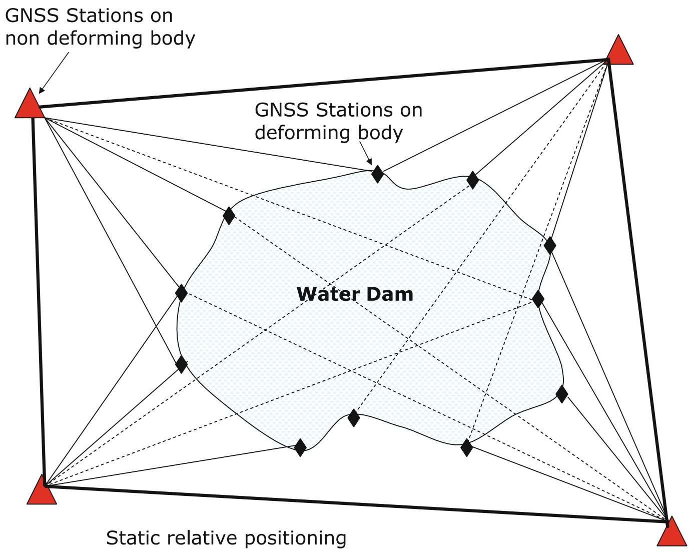

Fig. 9.8 Monitoring of deformation of a dam using static relative positioning. The triangles indicate control stations on the non-deforming surface. The diamonds indicate GNSS stations around the dam, which are being monitored for horizontal and vertical motion (*shift*)

The static relative positioning approach is potentially extremely useful for monitoring *environmental spatial variations*, e.g., deformation or land subsidence (e.g., Fig. 9.8). In this case, the control (reference) stations are set on a permanent non-deforming surface far from the deforming site being monitored, while the stations to be monitored are set on the deforming area. Relative positioning using *carrier phase* provides more accurate results to a few cm, depending on the accuracy of the control stations and on how the other errors are managed.

If the observations are undertaken for a longer period of say 1 h, depending on baseline lengths, the improved satellite geometry will enable the calculation of integer ambiguity and also reduce satellite geometry errors leading to more accurate results. Post-processing can also permit the use of *precise ephemeris* obtained within one to two weeks after the actual survey to give very accurate results. For example, the temporal monitoring (i.e., surveillance) of the position of a dam's wall will indicate any spatial changes such as horizontal or vertical shift, which can be analyzed to see whether the dam is deforming and posing a potential danger. The static relative positioning method is further useful for densification of existing control networks, monitoring earthquakes through measuring plate movements in crustal dynamics (Awange 2012) and oil rig monitoring (Schofield and Breach 2007, p. 339).

9.4.3 Real-Time GNSS (RTGNSS)

In Sect. 9.4.1, a decimeter accuracy for a stand alone receiver was said to be achievable by taking observations for 30–45 min using code observations. It was also pointed out that future modernized GNSS satellites are expected to improve positioning accuracy as a results of improved satellite orbit determination, receiver technology, additional user signal L2C, which would assist in modelling ionospheric errors, and additional ground monitoring stations. Although higher accuracies can be realized through post-processing of data, i.e., as done for precise point positioning (e.g., El-Rabbany 2006, p. 68), more and more users require these higher accuracies to be achieved in real-time. With such demands, receiver manufacturers are responding by coming up with receivers capable of delivering cm-level accuracy in real-time. More recently, position solution accuracy and speed have advanced to the point where centimeter-precision coordinates are available within seconds, and millimeter precision is available for daily solutions (Hammond et al. 2011).

An example is the NASA Global Differential GPS (GDGPS) System, which has been fully operational since 2000. It is a complete, highly accurate, and extremely robust real-time GPS monitoring and augmentation system that uses a large ground network of real-time reference receivers, innovative network architecture, and award-winning real-time data processing software to give decimeter-level (10 cm) positioning accuracy and sub-nanosecond time transfer accuracy anywhere in the world, on the ground, in the air, and in space, independent of local infrastructure.[2] Another example is the hand-held Mobile Mapper 100 from Ashtech that combines internal high-grade antenna and processing capability to achieve cm-level accuracy.[3] This hand-held receiver is suitable in monitoring changes in perimeters and areas of environmental features with spatial variability.

Besides the requirement of real-time GNSS data, other environmental applications such as earthquake monitoring would prefer that such data be delivered at a higher sampling rate (e.g., 1 Hz or higher), and at a low-latency (e.g., an order of seconds or less (e.g., Hammond et al. 2010). Real-time data allow for real-time science and have a place in an increasingly real-time society. For example, today, it is possible for anyone to receive notification of hypocentral and moment tensor information for earthquakes, placed into geographic and tectonic context, within minutes of their occurrence (Hammond et al. 2010). Hammond et al. (2010) provide an illustration of the benefit of low-latency information as exemplified by people who live in the path of natural hazards and require information about catastrophic events to be delivered as quickly as possible. The ability to detect and characterize events rapidly can make all the difference in the critical minutes to hours that follow an event, as was the case in the catastrophic 2004 Sumatra and 11 March 2011 Tohoku-oki earthquakes and tsunamis where many lives were lost (Hammond et al. 2010, 2011).

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[2] http://www.gdgps.net/.

[3] Mobile Mapper 100. White paper: A break through in hand-held accuracy.

9.4.4 Differential and Augmented GNSS

9.4.4.1 Differential GNSS (DGPS)

In this approach, the procedure is theoretically identical to post-processed static relative positioning using *code pseudoranges*, except that everything happens in real-time. The solutions using differential corrections (DGPS) and post-processed relative positioning using code data both give identical results. Due to the fact that the user obtains realtime results, in addition to the two receivers, a *real-time data link, e.g., radio or mobile* is required. The purpose of the data link is to transmit the "*range corrections*" from the reference station to the roving receiver for it to correct its own measured pseudoranges.

In general, a DGPS system will comprise of the *reference sites* whose coordinates are already well known to a higher accuracy, having been already surveyed using GPS carrier phase; a receiver measuring code or carrier phase pseudo-ranges, computing and transmitting the corrections; and a data link for transmitting the differential corrections using different radio frequencies. The reference station also monitors the integrity of the system and is often a permanent site with continuous power supply and automated equipment. There can be several reference sites whose coordinates are known in a DGPS system, of which there are two types;

1. the user's own independent reference station, which essentially means the user has to purchase an additional receiver, thereby incurring additional costs, and
2. commercially owned reference stations which charges users to access transmitted signals, e.g., Fugro in Australia.

Users of commercially owned DGPS only require one receiver, a data link and the cost of accessing the data. Japan's GEONET (GPS Earth Observation Network System) is comprised of more than 1500 receivers dedicated to GNSS-meteorology and geodynamic studies. In Australia, the National Collaborative Research Infrastructure Strategy (NCRIS) is currently establishing a nation-wide geodetic continuous operating reference stations (CORS) network consisting of 126 stations. These commercially owned systems are discussed in detail in Sect. 9.5.

The *user's station* is comprised of the receiver, with data link software to apply corrections to its uncorrected pseudoranges. Fax, telephones or mobile phones are also applicable in addition to radio as data links are range dependent, while other systems are line of sight dependent. Data link frequency bands vary depending on the baseline range while the data is transmitted from the reference to a roving station using a standard format called Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104 Format). With DGPS, the achievable accuracy using code pseudorange from a single frequency (L1) is in the range 3–5 m (US Army Corps of Engineers 2007).

This accuracy, however, is dependent on the closeness between the user's (rover) and the reference stations. The separation distance should ideally be below 50 km in order to assume that the satellite signals at both the rover and the reference stations are affected by the same errors. Users also have to be aware of data latency (time-delay in the reception of the corrections by the rover, i.e., 0.25–2 s). When carrier phases are used instead of code measurements, a real-time carrier phase differential GPS is achieved that provides positioning to a few centimeters accuracy (see Sect. 9.4.6).

9.4.4.2 Augmented GNSS

For applications that are more than 1000 km from a reference station, the DGPS approach discussed above is limited, thus paving way to *Wide Area Differential GPS (WADGPS)*. WADGPS has a global or regional coverage of reference stations required to model *atmospheric* and *orbital errors* that suffices for long baselines, and are classified into *Ground Based Augmented Systems (GBAS)* and *Satellite Based Augmented Systems (SBAS)*. GBAS, which uses ground-based stations, are useful for real-time applications. For multiple reference stations, RTCM SC-104 pseudorange corrections are received onboard the roving receiver from n reference stations (up to approximately 400 km). The pseudorange observations at the roving receiver are combined with each set of corrections to provide n independent solutions that are then combined in a conventional 3D adjustment to provide an additional estimate of the roving receiver's position. The accuracy of the roving receiver, similar to the DGPS case, will depend on its distance from the reference stations. For Government provided GBAS, the services are free to the users while subscription is required for privately delivered GBAS. Examples of GBAS are the Australian Maritime Safety Authority (AMSA) that has been operational since 2002 and offers maritime services to users, and the Nationwide Differential GPS (NDGPS) that is being expanded to cover all surface areas of the United States to meet the requirement of surface users.

SBAS send DGPS corrections to remote areas (e.g., areas out of reach of ordinary DGPS or GBAS such as oceans). Unlike a DGPS system where the data is transmitted via radio links, SBAS transmits data via geostationary communication satellites. These corrections are transmitted on a similar frequency to GPS satellites, thereby alleviating the need for additional software from the users. In Europe, the EGNOS geostationary satellites augment the GPS and GLONASS systems to provide wide area differential corrections. In US, The Federal Aviation Authority (FAA) developed the Wide Area Augmentation System (WAAS) to improve the accuracy, integrity and availability of GPS so that it can be a primary means of navigation for aircraft enroute and for non-precision approaches, thereby improving the real time civil accuracy of GPS to 7 m (Schofield and Breach 2007, p. 362). WAAS is also used in many other civil applications.

Examples of DGPS/WADGPS Companies include Fugro, who operates the Omnistar and Starfix systems, Racal who operates Landstar and Skyfix, and Western Geophysical who operate SARGAS. Other WADGPS systems are as discussed in Awange (2012).

9.4.5 Rapid Positioning Methods

Rapid GNSS positioning using carrier phase pseudorange includes techniques such as *rapid static or fast static surveys*, *stop-and-go surveys*, and *kinematic surveys*. Rapid or fast static survey are usually post-processed while stop-and-go and kinematic survey can be used in post-processing or in real-time modes of operation. Whereas for static surveying (see Sect. 9.4.2), ambiguity is resolved through long term averaging and a simple geometric calibration principal resulting in the solution of the linear equation that produces a resultant position, a variety of physical and mathematical techniques have been developed for rapid methods (US Army Corps of Engineers 2007). The physical methods include;

- static occupation of a known point (e.g., previously positioned points, i.e., known baselines) for over 30 s,
- static measurement at another known point on the baseline,
- static occupation of an unknown baseline (e.g., fast-static occupation time), and
- static occupation of an unknown baseline and swapping of reference-rover receivers for 2–4 min (i.e., between known and unknown points).

A mathematical approach adopted by most GPS systems used today is the ambiguity resolution *on-the-fly* (while moving). This technique is common for most real time kinematic (RTK) applications. *Rapid-static* or *fast-static surveys* are essentially the same as static surveys but make use of shorter station occupation times. In this approach, one or more roving GPS receivers occupies all *unknown stations* while at least one receiver (reference station) is stationary at a known control station all the time (Fig. 9.9). The rapid nature of this type of survey compared to static surveys is due to the rapid solution of the integer ambiguities, making use of *all observable satellites*, *single or both dual-frequency L1/L2*, and *carrier phase data*. Although fast-static relative positioning is accurate and economical where there are many points to be surveyed and offers more efficient positioning than conventional static relative positioning, the accuracy is usually slightly lower at the centimeter level. It is, however, suitable for short baselines where systematic errors such as atmospheric and orbital factors are considered identical and can be differenced.

Due to the special processing algorithm used for solving the integer ambiguities, at least four satellites need to be tracked continuously. The technique is only effective over short ($<$10–20 km) baselines and the observation occupation time depends on the number and geometry of the satellites visible. Station occupation time vary between 2 and 10 min with a data sampling rate every 5 s, depending on the distance to the base as well as the satellite geometry, see e.g., El-Rabbany (2006, p. 74) and US Army Corps of Engineers (2007). Redundant observations to more than four satellites with good geometry help improve the solution of the ambiguities and reduce the time required to achieve a sufficiently accurate position. While moving from one station to another, the receiver can also be switched off to conserve power. For static and fast-static satellite surveying, the effect of high PDOPs because of poor geometry is less significant since the observation time is normally longer (2–60 min), thereby guaranteeing a better or improved satellite geometry.

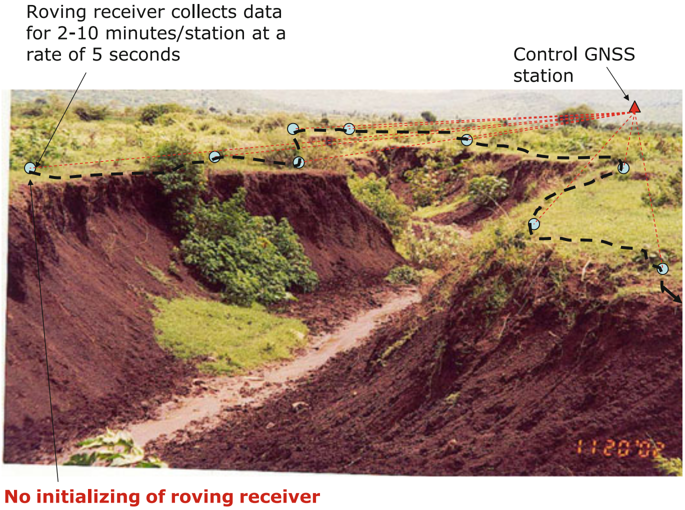

Fig. 9.9 Monitoring of the extent of erosion using fast static positioning. The triangle indicates the control station while the circles indicate the positions occupied by the roving receiver

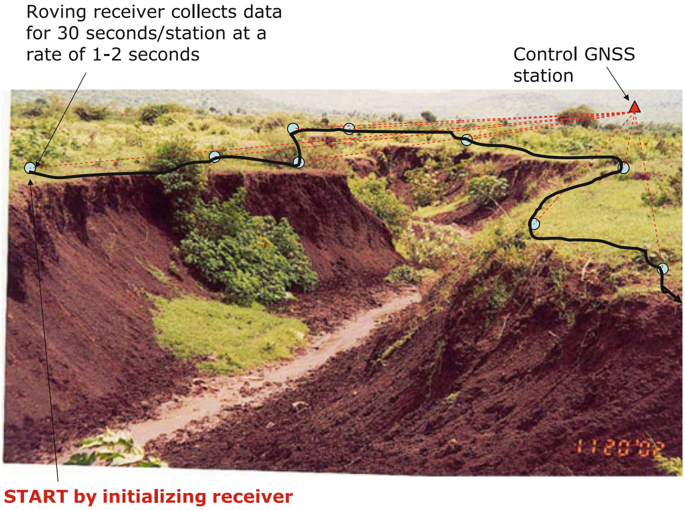

Fig. 9.10 Monitoring of the extent of erosion using the stop-and-go positioning method. The triangle indicate the control station while the circles indicate the positions occupied by the roving receiver. Initialization has to be done at the first station and a lock on four or more common satellites maintained

The *stop-and-go* method is a mixture of pure kinematic and static positioning. A series of points are positioned with respect to the reference receiver by moving the roving receiver sequentially to the points (see Fig. 9.10). To initialize the survey, the rover receiver has to remain static (e.g., at the first station to be positioned) for a certain time to allow for a solution of the integer ambiguities. The slightly longer period required for the initialization is to enable the satellite geometry to improve. Essentially, the initial static time is the same as that required for a fast-static survey. However, the initialization time can be greatly reduced by the occupation of a known station.

After initialization, the roving receiver is moved to the next station while continuously tracking the common (same) satellite signals. Initialization can also be achieved through reference-rover antenna swapping, by observing static data at another known point on the network, or by observing on a known baseline. At a given station, an observation time of only one or a few epochs (period of observations) is necessary to obtain a precise position as the integer ambiguities are already solved during the initialization phase. The rover typically collects data for a period of 30 s at a sampling rate of 1–2 s before moving to the next station (El-Rabbany 2006, p. 75). In this way, by moving the roving receiver, a series of stations can be coordinated sequentially. Similar to the fast-static survey, the stop-and-go survey technique requires at least four satellites to be continuously tracked. If lock to one of the minimum four satellites is lost, the roving antenna must be re-initialized by *returning the roving receiver to a previously surveyed point*, or *preferably to a known station*.

With the availability of fast ambiguity resolution techniques, the stop-and-go survey technique is best suited to coordinate a large number of stations (e.g., survey grid or precise mapping). However, there must be open sky in order to avoid frequent loss-of-lock of the satellite signal. It is essential for this technique that the satellites' signals can be continuously tracked throughout the survey. This method has an advantage over static positioning since it reduces observation time and is ideal for topographic surveys, such as the mapping of habitats, since it offers an accuracy of 2–3 cm for a baseline of 10–15 km (real-time or post-processed). The disadvantage of the method is the reliance on locked satellites (i.e., the satellites detected by the receiver) and having to re-initialize once loss of lock occurs.

Kinematic surveying operates with the same principle as the stop-and-go method, only that in this case, there is no stopping but the roving receiver is in continuous motion. Unlike fast static approach, the receiver is not switched off while in motion. In Fig. 9.11 the use of kinematic survey, particularly when a linear feature is being mapped is shown. The accuracy of kinematic surveys is, however, lower than that of stop-and-go, since some of the common errors encountered cancel with improved satellite geometry in stop-and-go.

9.4.6 Real-Time Kinematic (RTK)

As the name suggests, RTK is capable of delivering real-time positions in the field. Similar to the other rapid positioning techniques discussed above, RTK also requires more than two receivers, with one being placed at a known station (also called base station). Unlike the fast static and stop-and-go, it uses the DGPS principle discussed in Sect. 9.4.4. The base receiver remains stationary and has a transmitting radio link

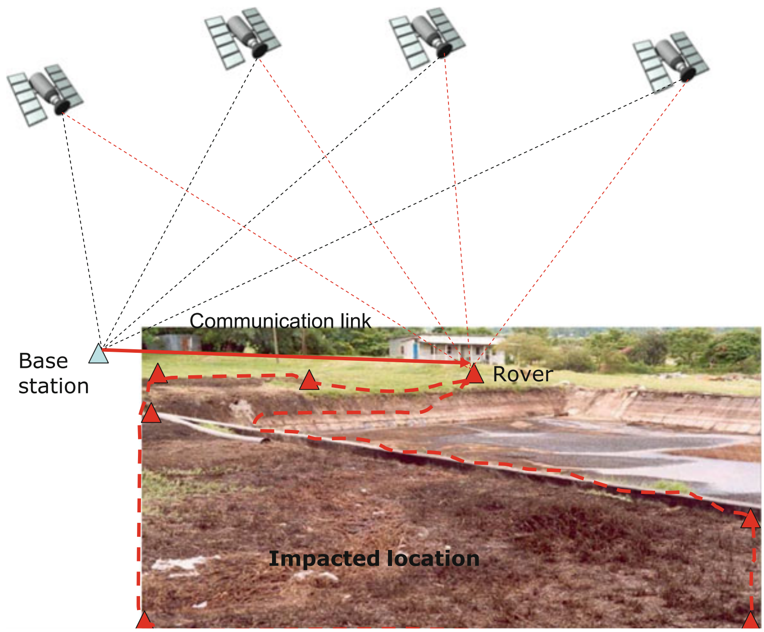

Fig. 9.11 RTK mapping of the boundary of an impacted location to monitor its spatial extent. The base receiver remains stationary and transmits raw data together with its position via the communication link to the roving receiver

while the roving receiver is in motion and has a receiving radio link (see Fig. 9.11). The base receiver samples data every second and transmits these raw data together with its position via the communications link (e.g., satellites, mobiles or radio) to the roving receiver. Using its radio receiver, the rover receives the transmitted data from the base receiver and uses in-built software to combine and process the GNSS measurements obtained at both the base and roving receivers to obtain its position (El-Rabbany 2006, p. 78).

Some GPS manufacturers provide a hand-held controller that the surveyor can use to operate both the roving and the base receivers. Normally, the surveyor carries the roving receiver attached to the radio link in a back pack. The method requires the fixing of the integer ambiguities at the start of the survey (initialization) before undertaking the survey. Ambiguities can be initialized through the methods discussed in Sect. 9.4.5. Once the initial ambiguity has been fixed, the roving receiver can be moved. Any loss-of-lock due to obstructions makes a re-initialization necessary.

Most kinematic survey algorithms use the ambiguity resolution on-the-fly as it allows integer resolution while the antenna is moving. With this approach, no initial *static initialization* is required. Once the integer ambiguities have been fixed, all previous measurements can be calculated back to obtain precise coordinates for all positions. This surveying technique, which requires dual frequency observations (L1/L2), makes it possible to perform certain precise environmental monitoring tasks in a kinematic mode, e.g., monitoring a proposed construction of linear features such as roads for the purpose of assisting environmental impact assessment. The integer ambiguity is fixed and preserved for at least four (preferably five) satellites during the motion of the roving receiver. The accuracy of this method is about 2–5 cm with a possibility of improvement if a longer period of station observation (i.e., 30 s) is adopted (El-Rabbany 2006, p. 78). Compared to the kinematic survey, which allows post-processing (i.e., post processed kinematic, PPK), the accuracy of RTK is a bit lower. This is due to the time lag in the transmitted data reaching the rover, whereas post-processing enables the matching of data, correcting it for some errors and use of precise ephemeris.

In order not to confuse real-time DGPS and RTK, it should be remembered that DGPS uses code pseudorange corrections, improving the positioning accuracy from 15 to 5 m,[4] while RTK uses raw carrier phases and codes. RTK facilitates the efficient establishment of a series of points in open areas, and even in areas of some overhead obstructions due to the advent of fast ambiguity resolution techniques. Unlike DGPS, the fundamental principle of RTK is that the carrier phase and code data from the reference station are transmitted to the roving receiver, which then uses the data from both the roving and reference receivers to form double difference observations and compute the position of the rover. Telemetry links form a critical component of RTK systems, over which the data from the reference receiver are transmitted to the rover. High baud rates and high radio frequencies are required, which limit the extent of the surveys. Reference (control) stations can normally be obtained from local surveying offices or the appropriate government agencies. The accuracies of the control points will contribute to the accuracies of the user's derived position, particularly when using relative, DGPS or RTK methods.

Network RTK: Since most RTK systems require the roving receiver to be within 10 km of the base station (assuming similar atmospheric conditions), use of multiple base stations, i.e., network RTK, provides an alternative for baselines more than 10 km long. Ambiguities must still be resolvable within seconds or instantaneously, up to baselines of 50–100 km in length, which requires the consideration of the orbital and atmospheric (tropospheric and ionospheric) errors. An approach currently receiving wide attention around the world uses the virtual reference station. In this approach, the roving receiver is located within the bounds of three or more reference stations and the observation errors modelled according to the approximate position of the rover. Rizos (2001) identified some advantages of network RTK over single-baseline RTK as;

1. rapid static and kinematic GPS techniques that could be used over baselines many tens of kilometers in length,
2. instantaneous (i.e., single-epoch) on-the-fly ambiguity resolution algorithms could be used for GPS positioning, at the same time ensuring high accuracy, availability and reliability for critical applications, and

[4] Some providers, such as Fugro in Australia, have started using carrier phase pseudorange corrections to deliver sub-centimeter accuracy.

3. rapid static positioning is possible using lower-cost, single-frequency GPS receivers, even over baselines tens of kilometers in length.

9.5 Environmental Surveillance: CORS Monitoring

In Awange (2012), *surveillance* is introduced as the systematic observation of variables and processes with the aim of producing *time series*. Indeed, most environmental events require *continuous monitoring* in order to analyze time series maps. Such environmental processes are those that result in changes with time, such as *plate tectonic motions*, *land submergence* or *changes in sea levels*. As an example, let us consider a locality like Perth (Australia), which uses ground water for its domestic and industrial activities. In order to monitor the environmental impacts of groundwater extraction, i.e., whether there is some land submergence due to water extraction, continuous observation of locations of known heights can provide time series maps, which can be analyzed to assess any sinking of land.

Currently, GPS stations provide such capability in what is known as a Continuous Operating Reference Stations (CORS). CORS data support high-accuracy three-dimensional positioning activities useful in environmental monitoring of spatial motions in time. Its data are also used by geophysicists, meteorologists, atmospheric and ionospheric scientists, and others in support of a wide variety of applications (Snay and Soler 2008). For example, Maryam et al. (2009), Motagh et al. (2007), Anderssohn et al. (2008) undertook surveillance monitoring of land subsidence in northeast Iran using both GPS and InSAR[5] and obtained a 19 cm/year subsidence using both methods (see Awange et al. (2010) for more details).

A CORS station is a stationary GNSS receiver which is continually collecting data from visible GNSS satellites on a 24 h basis in order to produce its three-dimensional coordinates (e.g., Fig. 9.12). CORS networks vary in size ranging from regional, national to global scales (e.g., the International Global Navigation Satellite System Service (IGS)). Each individual CORS station is positioned to a very high degree of accuracy using precise GNSS, satellite laser ranging (SLR), and very long baseline interferometry (VLBI) discussed in Awange and Kiema (2013), thereby enabling them to be used as reference stations to position other points, besides continuously providing their own positions. Individual users can also benefit from CORS networks by acquiring data from the CORS stations within their vicinity to achieve more accurate results (see Sect. 9.4.4). Perhaps of importance to environmentalists is the question posed by Rizos (2001):

> *What if, instead of broadcasting RTK corrections and placing the onus of obtaining a final solution on users and their equipment, users' coordinates are determined by a service provider?*

This is the client-server approach envisaged by Rizos (2001) who then states:

[5]Interferometric synthetic aperture radar.

Fig. 9.12 A GEONET GNSS-based CORS station in Japan. *Source* Geospatial Information Authority of Japan

Final (position) solutions for all real-time (logged) users could be simply computed as a by-product of the continuous network processes, all the time satisfying the quality and integrity criteria implemented at the network administrator level. Note that improved accuracy and reliability of the user coordinates can be expected if GPS data is processed in the network mode, rather than as individual baselines as is the case for standard RTK-type techniques. In addition, precise ultra-rapid IGS ephemerides can be used in the network computations instead of the broadcast ephemeris.

The feasibility of Rizo's proposed model would enormously benefit environmentalists who would then have to only send their data to a central processing unit and receive their final products in the form of their receiver positions. Such a mode of GNSS operations already exist. In Australia for example, AUSPOS (Australian online GPS processing service) enables users to send their data to a central processing unit at Geoscience Australia via the Internet (AUSPOS 2006). The processing software thereafter, chooses three CORS stations that are near the user's observing station and employs them to process the user's position. The results are then sent back to the user via email. In the US, the OPUS (Online Positioning User Service) has performed similar functions as AUSPOS since March 2001 (National Geodetic Survey 2006).

Other examples of CORS-type networks include the Japanese GEONET (e.g., Fig. 9.14), Germany's Satellite Positioning Service (SAPOS), and the US's National Spatial Reference System (NSRS), which comprised a network of over 1,350 sites in 2008 and is growing at a rate of about 15 sites per month (Snay and Soler 2008). Snay and Soler (2008) summarize the history, applications, and future prospects of the NSRS CORS network by describing the more important contributions of the CORS system to the scientific community. Some of the uses of CORS documented e.g., by Snay and Soler (2008), which may be of benefit to environmental monitoring tasks include (Fig. 9.13);

- Upgrading national geodetic reference systems (e.g., Sect. 9.6). Snay and Soler (2008) report on the upgrading of the US based national geodetic system with the help of CORS coordinates that were held fixed in the adjustment process.
- Assessing GNSS observational accuracies. With a well-established network of CORS stations, it is possible to design experiments that are aimed at improving GNSS positioning methodologies within a relative positioning framework, e.g., Snay and Soler (2008).
- Multipath studies. In this regard, the CORS network could be used for instance to investigate further possibilities of minimizing positioning errors resulting from

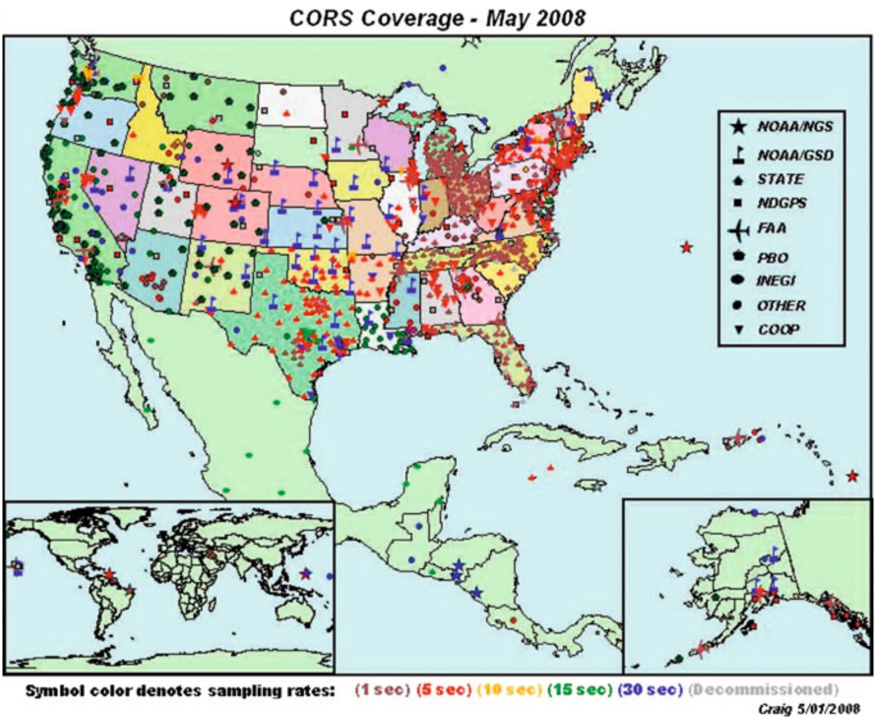

Fig. 9.13 NSRS CORS stations in May 2008. *Source* Snay and Soler (2008)

multipath. Snay and Soler (2008) report on how CORS stations were used to evaluate the amount of multipath occurring at each of the more than 390 sites, where the most and least affected sites were identified in the network, different receiver/antenna combinations compared, and those sites that appeared to be severely affected by multipath more closely investigated.

- Crustal motion monitoring. This could be the most visible environmental monitoring application of CORS stations where the horizontal and vertical motion of the Earth's surface is monitored to mitigate, e.g., the impacts of earthquakes, tsunamis and other disasters resulting from plate motions, see e.g., Awange (2012). For this, many CORS stations provide velocities that are useful in indicating plate motions and time information.
- Sea level change monitoring. The variations of vertical crustal velocities at CORS sites near tide gauge stations may be used to determine the "absolute" sea level change with respect to the International Terrestrial Reference Frame (ITRF). This type of analysis was impossible to conduct before the proliferation of CORS in coastal areas (Snay and Soler 2008). This application is discussed further in Awange (2012).
- Atmospheric monitoring. CORS are currently contributing to the new field of GNSS-meteorology, e.g., Awange (2012). Besides their application to GNSS-meteorology, CORS station could be useful in ionospheric studies as discussed by Snay and Soler (2008).
- Support of remote sensing applications. CORS stations have been used to support remote sensing applications such as the accurate positioning of aircraft employed in aerial mapping in order to improve the reliability of photogrammetric restitution, especially for large-scale aerial surveys over remote or inaccessible terrain. It may then be implemented for geolocating landmarks from the air with digital cameras, as well as being applied to a broad range of mapping technologies, such as scanning radar, light detection and ranging (LiDAR), inertial systems, interferometric synthetic aperture radar, and/or sonar (Snay and Soler 2008). These remote sensing techniques are discussed in detail subsequent chapters.

To date, Japan's distribution of CORS stations is the most numerous and densest in the world. This network, known as *GEONET* (Fig. 9.14), is used mainly for geodynamic/geophysical monitoring around Japan where four tectonic plates are interacting with each other, i.e., the monitoring of earthquakes and volcanic hazards (Matsuzaka 2006).

Matsuzaka (2006) points to the fact that 1200 GEONET CORS stations with an average spacing of 20–30 km between stations are operational in order to realize the system's desired use. This network has been operational since 1994 under the control of the Geospatial Information Authority of Japan (GSI), providing precise daily coordinates of all stations, with which displacement and strain rates are calculated nationwide, thereby revealing the various characteristics of tectonic deformation in the Japanese islands (Sagiya 2005). Japan has also undertaken several measures to improve the quality of data collected, including creating a double cylindrical structure of observation pillar to reduce thermal effects, unification of antenna types to

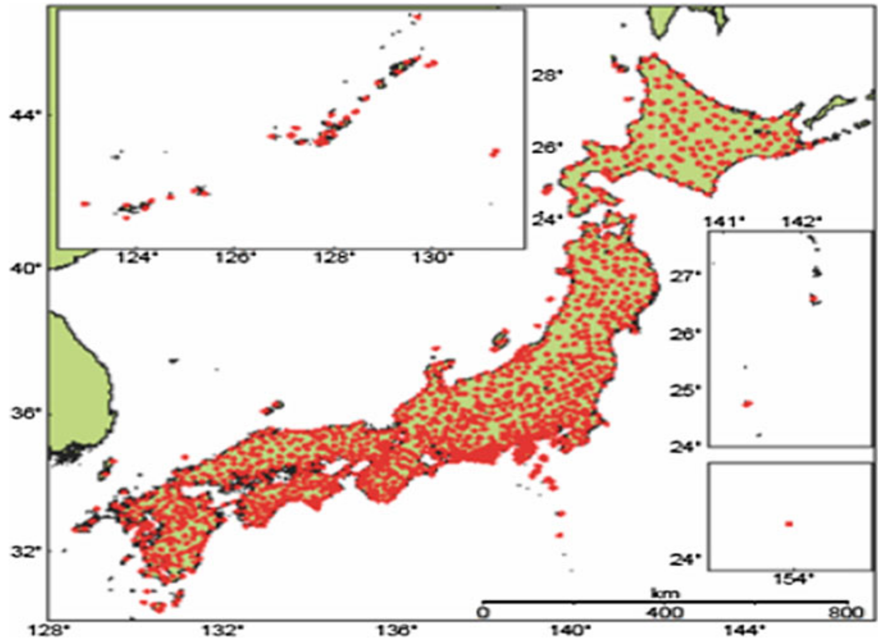

Fig. 9.14 GEONET CORS stations. GEONET data are used in various disaster related meetings and geophysical model estimation of crustal activities and thus are reflected in the decision making process to cope with the disaster as well as the scientific researches. *Source* Matsuzaka (2006)

reduce multipath and a better analysis strategy to obtain more reliable and accurate solutions (Matsuzaka 2006). A typical GEONET station consists of a 5 m pillar, chokering antenna, 24 h observations, 1 h sampling rate and real-time data transfer (see, e.g., Fig. 9.12). These attributes enable Japan to measure *tectonic plate movements* and “slips” occurring along fault lines to a high degree of accuracy (post-processed $\pm$ 2 mm) (Matsuzaka 2006).

SAPOS comprises a network of more than 250 CORS stations[6] run by the German State Survey for the purpose of supporting cadastral surveying, engineering surveying, private industry sector applications (e.g., transport fleet management), emergency guidance systems (e.g., police, fire and radio) and deformation measurements (SAPOS 2009). The average spacing between the stations is 50 km. Various quality control measures carried out allow a precision of the order of 1 cm–5 m in real-time positioning, see e.g., Wolfgang (2005).

The US presents two scenarios of CORS made up of 1450 stations (as of May 2010): the National CORS system made up of over 988 stations and run by the National Geodetic Survey (NGS), and a collaborative network comprising more than 200 organizations.[7] CORS GPS observational data are freely provided to the user

[6] http://www.sapos.de/pdf/Flyer/2004Flyer_e.pdf.

[7] http://www.ngs.noaa.gov/CORS/.

community via the Internet and are capable of supporting high-accuracy positioning requirements. In addition to enhancing geospatial positioning, applications using CORS data include the following (Stone 2006);

- a critical role in defining the nation's geodetic reference system,
- *the ability to characterize the free electron content of the ionosphere*, and
- an important *source of precipitable water vapour input to meteorological forecasts*.

The last two are environmental monitoring related tasks.

CORS Networks in Australia are at the development stage. Australia-wide, there are several CORS networks in place. The Australian Fiducial Network (AFN) consists of 8 CORS stations, which together with a further 8 CORS stations, both on the Australian continent and offshore, form the Australian Regional GPS Network (ARGN) (Geoscience Australia 2009). The network has reached a global accuracy of a few centimeters, which is sufficient for the designed purpose. Besides this, several Australian states and cities have begun installing their own CORS networks, e.g., Victoria's VICPOS. Some of the CORS stations in VICPOS are also incorporated in MELBPOS, a CORS network specifically for Melbourne. Sydney also has a specific CORS network named SYDNET.

Densification of the Australian CORS network is currently ongoing, as indicated in Fig. 9.15, which shows the proposed Australian CORS network, which is designed to cater for the needs of most of the populated areas of the country. This network

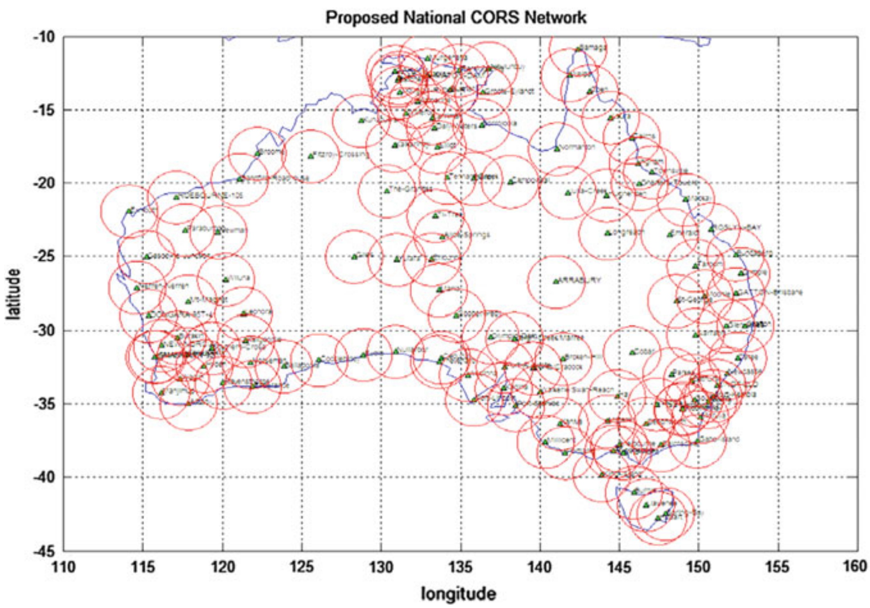

Fig. 9.15 Coverage by the proposed Australian national CORS network (baseline length 200 km). *Source* Wallace (2007)

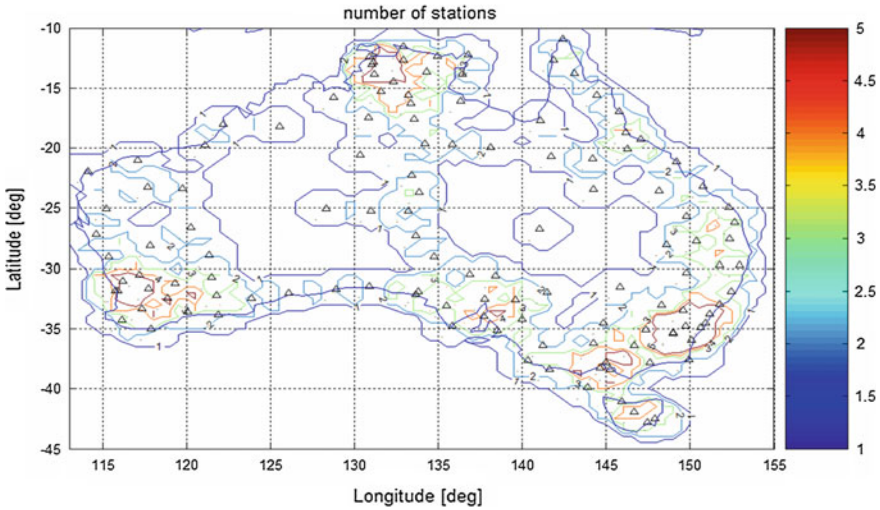

Fig. 9.16 Station overlap for 200 km baseline. *Source* Wallace (2007)

would allow a maximum baseline length of 200 km spatial coverage. To be able to position with the online based AUSPOS, the number of stations that a user can access within the proposed baseline length of 200 km are illustrated in Fig. 9.16.

9.6 Coordinate Reference System

The preceding sections have dwelt with the measurement techniques and variables used with GNSS. What has not been discussed at length is that these measurements have to refer to some coordinate system. From a social perspective, human beings have names that identify them, as do places and biological species. When we talk of GNSS providing locations, how therefore do we refer to them? The answer lies in the concept of a Coordinate Reference System, which is comprised of a *datum*, *coordinate system*, and *map projection*.

9.6.1 Datum

A datum, a *mathematical figure* (ellipsoid) that enables measurements and computations to be undertaken on the surface of the Earth, is defined by its size, shape, location and orientation, and its relation to the geoid by means of geoid undulation and deflection of the vertical (Leick 2004, p. 29). This is necessitated by the fact that the topographical surface of the Earth is irregular and unfit to be used for computations. For simple tasks, a sphere is normally used to approximate the Earth. In more precise work, such as GNSS measurements and computations, an *ellipsoid of revolutions* (e.g., Fig. 9.17) is normally used. An ellipsoid of revolution is simply a bi-axial ellipsoid defined by the axes $\{a, b\}$ rotated around the minor axes $\{b\}$. Besides these axes, the ellipsoid has to have an origin.

For the case where this origin coincides with the center of mass of the Earth, it is called a geocentric ellipsoid. The ellipsoid thus becomes a reference surface for horizontal positioning. A well-positioned reference ellipsoid has two axes defining the dimensions of the ellipsoid, three parameters defining its origin, and three parameters defining the orientation in space. All together, these form a *geodetic datum* (El-Rabbany 2006, p. 48) or simply a *reference ellipsoid*. A geodetic datum as defined above will therefore give the horizontal position (two-dimensional) of any location on Earth.

Some environmental monitoring tasks, such as land subsidence, changes in sea level, or the amount of siltation in a lake, require information on heights with respect to some reference. This reference is often known as the *vertical datum*. Its definition uses the sea level. If sea level in a coastal area is measured by tide gauges and averaged over a period of time (i.e., years), a *mean sea level* MSL is obtained. Now, let us project this MSL through the Earth such that it passes through the continents (e.g., Fig. 9.18), as if there were canals all the way through the continents. The obtained surface is called a *geoid*, and is defined as an equipotential surface approximating mean sea level, and is the *vertical datum*. Height measurements in local systems are normally measured with respect to this datum or simply the MSL, hence it is common to give readings above MSL.

Unlike the traditionally used heights (orthometric heights), which are normally referred to MSL as a reference, GNSS heights are normally measured with respect to

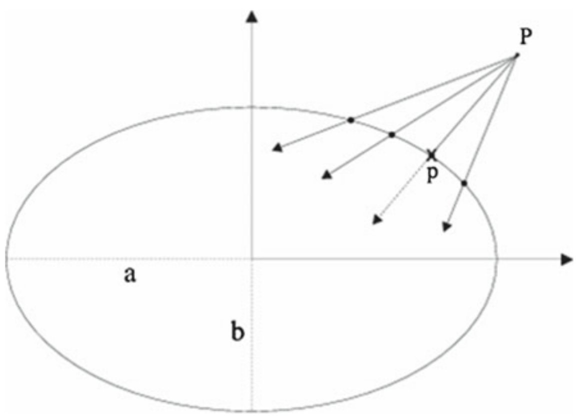

Fig. 9.17 Reference ellipsoid: Point *P* on the Earth's topographic surface and its corresponding point *p* on the *Reference ellipsoid of revolution* with semi-major axis *a* and semi-minor axis *b*

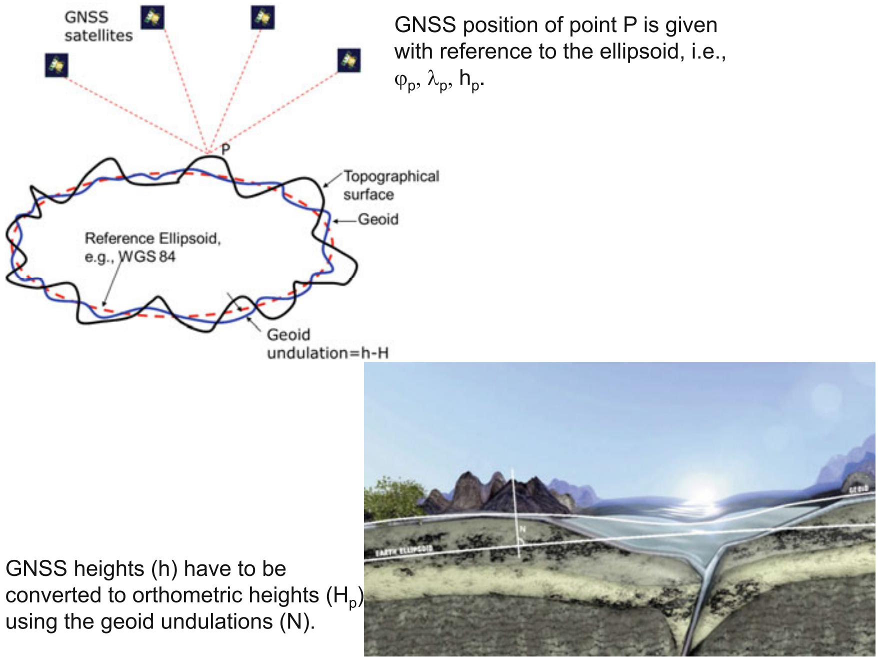

Fig. 9.18 Vertical datum—the geoid

the reference ellipsoid. The shape of the geoid is complex, determined by the Earth's gravity field. Therefore, when using GNSS for vertical positioning, knowledge of the geoid-ellipsoid separation (i.e., (N) in Fig. 9.18), is highly desirable, if not essential. For surveys over small areas (e.g., up to 10 km), it is often acceptable to use an approximation to the geoid. This method makes use of the fact that the geoid height does not vary that much over these distances.

In traditional surveying methods, the horizontal positions and vertical positions are determined separately. With GNSS positioning, however, both the vertical and horizontal positions are obtained from the same set of measurements. For instance, the position of point P in Fig. 9.18 would be given by GNSS as $\{\phi, \lambda, h\}$. The height h is, however, measured with respect to the reference ellipsoid. Of interest is the height with respect to the geoid, i.e., H. In this case, we have to subtract the geoid undulation N from the measured ellipsoidal GNSS height h to obtain the physical height H above the MSL (geoid).

9.6.2 Coordinate Systems and Transformations

A *coordinate system* is a set of rules that state the correspondence between coordinates and points; a *coordinate* is one of the set of the N numbers individuating the location of a point in an N-dimensional space. A coordinate system is defined once a point of known *origin*, a set of N lines, known as *axes*, all passing through the origin and having a well-known relationship to each other, and *a unit length* are established (Prasad and Ruggieri 2005, p. 17). A coordinate system is thus a set of rules that specify the locations (also called the coordinates of points), see e.g., Fig. 9.19 El-Rabbany (2006, p. 49). Coordinate systems are normally:

- One-dimension (e.g., the 1D heights or sea level tide gauge readings); two-dimensions (e.g., the 2D position of points in Easting and Northing); or three-dimensions (e.g., the 3D position of points in latitude ϕ, longitude λ, and height h). GNSS positioning will always give 3D coordinates of points either in geographical form (ϕ, λ, h) or Cartesian form (X, Y, Z). Transformation between geographical and Cartesian are documented, e.g., in Awange and Grafarend (2005), Awange et al. (2010).
- Refer to reference surfaces. Many countries have their own local reference surfaces (i.e., their own origins and axes parameters). For GNSS positioning, the reference surface is always an ellipsoid of revolution (see, definition of datum in Sect. 9.6.1).

A *reference system* is the conceptual idea of a particular coordinate system, whereas a *reference frame* is the practical realization of a reference system through observations and measurements (affected by errors), which means that a reference frame is a list of coordinates and velocities of stations (related to tectonic plate motion) placed in the area of interest, together with the estimated level of errors in those values (Prasad and Ruggieri 2005, p. 18). An example of a 3D geocentric coordinate system is the *Conventional Terrestrial Reference System (CTRS)* whose origin coincides with the center of the Earth. The z-axis points towards the conventional terrestrial reference pole (i.e., mean of the pole during the period 1900–1905), the x-axis points in the direction of the Greenwich meridian and the y-axis is perpendicular to the $x - z$-plane, thus completing a right-handed system (Fig. 9.19). To be of use, the CTRS must be positioned with respect to the Earth, a task often undertaken by assigning coordinates to selected points (stations) on the Earth's surface. The assignment of coordinates, i.e., realization, is often achieved using accurate geodetic techniques such as GNSS, VLBI and SLR e.g., Anderssohn et al. (2008).

The International Terrestrial Reference System (ITRF) is one of the CTRS commonly used and is realized through GPS and other geodetic measurements of globally distributed stations. It is maintained by the IERS (International Earth Rotation Service) under the auspices of the IAG (International Association of Geodesy) and is updated every 1–3 years to achieve the highest level of accuracy and, often refers to the particular time of updating, e.g., ITRF2005 as per 2005. This therefore means that ITRFs are dynamic in nature with the coordinates changing due to plate tectonic motions. They are only valid for a specific period (epoch) and incorporate velocity information to update other epochs.

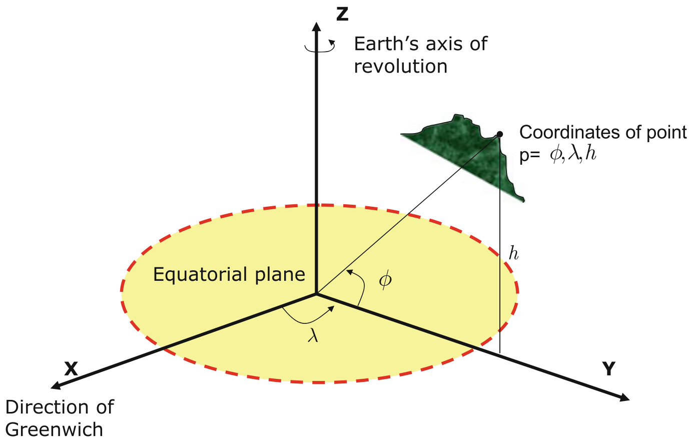

Fig. 9.19 A Coordinate System

The *World Geodetic System (WGS-84)* established in 1984 is a 3D system that is used in GPS positioning in an Earth-Centered Earth-fixed (ECEF) reference frame. It is defined as (Prasad and Ruggieri 2005, p. 22):

- Its origin is at the center of mass, the Z axis points towards the direction of the International Earth Rotation Service (IERS) reference pole (IRP), which corresponds to the direction of the BIH (Bureau International de l'Heure) Conventional Terrestrial Pole (CTP) at the epoch 1984.0 with uncertainty of 0.005" (i.e., arc seconds).
- The X axis is defined by the intersection of the IERS reference meridian and the plane passing through the origin and normal to the Z axis.
- The Y axis completes a right-handed, ECEF orthogonal coordinate system.

The satellite positions sent via the navigation message discussed in Awange (2012), i.e., the broadcast ephemeris, are with respect to the WGS-84 system. Any user whose position values used broadcast ephemeris will thus obtain the receiver's position in the WGS-84 system (El-Rabbany 2006, p. 52). The WGS-84 system was originally established using a number of Doppler stations and has since been updated to bring it to ITRF as close as possible (El-Rabbany 2006, p. 49). This has since seen the WGS-84 system evolve to being dynamic. If users work with the precise ephemeris obtained from the IGS (International GNSS Service), see e.g., IGS (2009), then their coordinates will be in the ITRF reference system.

Datum transformations are the conversion of coordinates from one form to another, i.e., WGS-84 to local systems. This is necessitated by the fact that old maps in most countries were done in local systems (e.g., separate horizontal and vertical datums). Normally, there exists transformation parameters that are used for these transformations, see e.g., Awange and Grafarend (2005). Most GNSS processing software have in-built transformation algorithms that undertakes this task.

Coordinate transformation is commonly used in photogrammetry, remote sensing and GIS and is adequately addressed in many textbooks, see e.g., Murai (1999), Moffit and Mikhail (1980), Wolf (1980), Luhmann et al. (2011), Schenk (2005), etc. Different types of coordinate transformations can be discriminated. For example, this may entail transformation from one two-dimensional coordinate system (x, y) to another two-dimensional coordinate system (u, v). It may also involve transformation from a two-dimensional coordinate system (x, y) to a three-dimensional coordinate system (X, Y, Z), or even transformation from one three-dimensional coordinate system (X, Y, Z) to another three-dimensional coordinate system (X', Y', Z'). Generally speaking, coordinate transformations are required to among other things;

(a) transform different map projections (see Sect. 9.6.3) employed in diverse GIS data sources to a unified map projection in a GIS database,
(b) correct and adjust for various systematic errors which occur during map digitization as a result of shrinkage or distortion of the map measured (see Awange and Kiema 2013);
(c) transform generated stereomodels from an arbitrary coordinate system to an integrated photogrammetric coordinate system during aerial triangulation (see Sect. 10.3.3), and
(c) produce geo-coded image through geometric correction of remote sensing imagery (see Awange and Kiema 2013).

Basically, coordinate transformation is accomplished through the selection and use of an appropriate transformation model (or mathematical equation), with a set of reference or control points. The control points are selected as *tic marks*, *reséau* or *ground control points*. Furthermore, the number and spatial distribution of the control points is important and is determined by the type of coordinate transformation being undertaken and the desired level of accuracy.

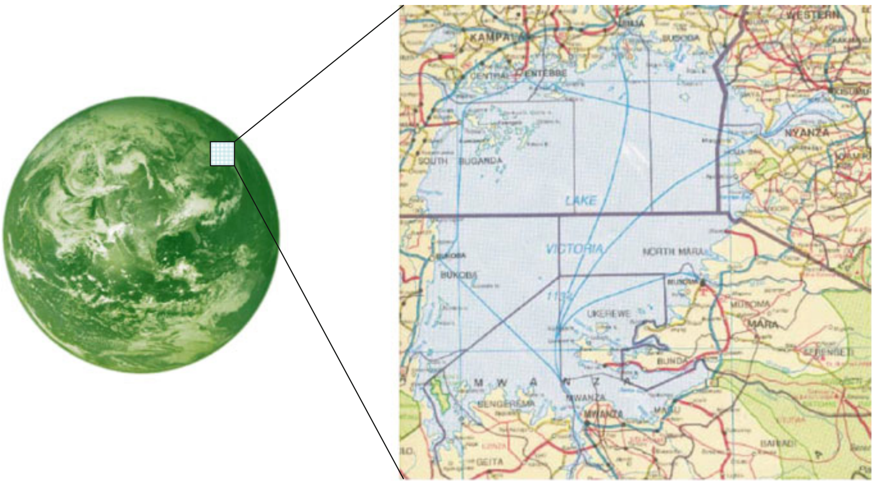

Fig. 9.20 Map projection, i.e., from a curved surface to planar surface

9.6.3 Map Projection

Finally, once the datum (ellipsoid of revolution) and the coordinate system for referencing the locations have been chosen, an appropriate mathematical method of transferring locations from the idealized Earth model to the chosen planar coordinate system must be chosen, a procedure known as *map projection*. Map projections are thus the representation of objects and information on a curved surface in a plane using mathematical and geometric relations (see Fig. 9.20).

9.7 Concluding Remarks

This chapter has presented some of the GNSS field techniques that are essential for measuring key indicators in environmental monitoring. Essentially, kinematic GNSS surveying refers to taking measurements while the receivers are 'on the move' and can be operated either in *single point mode* or *continuous mode*. In single point mode the user holds the antenna stationary over a point for a set period of time, normally between 10 s to 5 min, depending on the satellite geometry and the number of satellites visible. Over baselines of less than 5 km, this mode will generally deliver coordinate accuracies similar to fast static methods, although the antenna height errors are magnified due to the fact that the antenna is in motion and not fixed.

In continuous mode, the user may move around an area of interest logging data at time intervals suitable for the needs of the survey. This mode is good for topographic mapping (see Awange 2012), boundary definition, and other types of survey that may require rapid data collection within points surrounding a reference station. Over short baselines (<5 km) horizontal point accuracy is at the 1–3 cm level, depending on satellite geometry, number of satellites and the multipath environment. As with all GPS observation techniques, height accuracy is slightly worse.

Kinematic data can be post-processed (e.g., post-processing kinematics; PPK) or have results given in real time (real-time kinematic; RTK). PPK differs from RTK in the following ways:

- PPK surveys logs raw GNSS code and carrier phase data on the hard disks at their base and roving receivers while for RTK, base stations do not log data, while roving receivers log the *coordinates* of the points visited.
- A communication link is required for RTK systems between the base and rover receivers to transmit the raw phase data from the base to the rover, while for PPK, this is not required.
- Once the raw data has been received by the roving receivers in RTK, all data processing and analysis are done 'on board' whilst in the field, while PPK processing is performed back in the office using proprietary processing software.
- With a communications link comes additional hardware and firmware which make RTK systems more expensive than PPK systems.

- Post-processing in PPK enables the use of precise ephemeris from the IGS and the possibility of removing cycle slip errors, thereby giving more accurate results compared to RTK, which uses broadcast ephemeris.
- Advantages of real-time GNSS for environmental monitoring include rapid and efficient data collection that provide results in real-time.

In summary, real-time satellite positioning can be achieved at three levels of accuracy for navigation.

1. Low-accuracy, real-time positions are given by any stand-alone receiver.
2. DGPS uses telemetry of C/A-code pseudorange corrections to give improved ~2–5 m positioning and ~0.1m/s velocity accuracies of the roving receiver. This is of use in applications such as airborne magnetic surveying or remote sensing. Real-time DGPS is robust due to its use of the unambiguous codes, which are not as susceptible to loss of satellite lock as the carrier phases.
3. The highest accuracy real-time requirements, ~10 cm positioning and ~0.01 m/s velocity are offered by real-time pure kinematic relative GPS. Its applications include accurate marine and airborne navigation and precise hydrographic surveying. On land, detailed survey grids can be established in the field to better than 5 cm. This is an example of RTK, where the real-time capability requires only one visit to the field.
4. Kinematic surveys (Sect. 9.4.6) using carrier phases can position the roving receiver with respect to the stationary reference receiver to better than 10 cm.
5. GPS positioning accuracy depending on position mode and measurement types used are listed below:

    - Kinematic point positioning (code) ~15–20 m.
    - Static (autonomous) point positioning (code) 5–15 m. Expected to be 3–5 m with current modernization.
    - Kinematic relative positioning (DGPS) 3–5 m.
    - Kinematic relative positioning (carrier phase) <10 cm.
    - Static relative positioning (code) 0.5–1 m.
    - Static relative positioning (carrier phase) mm-cm level.
    - RTK surveying <10 cm.

References

Anderssohn J, Wetzel H, Walter TR, Motagh M, Djamour Y, Kaufmann H (2008) Land subsidence pattern controlled by old alpine basement faults in the Kashmar Valley, northeast Iran: results from InSAR and levelling. Geophys J Int 174:287–294. doi:10.1111/j.1365-246X.2008.03805.x

Auspos (2006) Australian online GPS processing service. http://www.ga.gov.au/bin/gps.pl. Accessed 14 May 2009

Awange JL (2012) Environmental monitoring using GNSS, global navigation satellite system. Springer, Berlin

Awange JL, Grafarend EW (2005) Solving algebraic computational problems in geodesy and geoinformatics. Springer, Berlin

Awange JL, Kiema JBK (2013) Environmental geoinformatics, monitoring and management. Springer, Berlin

Awange JL, Grafarend EW, Paláncz B, Zaletnyik P (2010) Algebraic geodesy and geoinformatics, 2nd edn. Springer, Berlin

El-Rabbany A (2006) Introduction to GPS global positioning system, 2nd edn. Artech House, Boston

Geoscience Australia (2009) Australian regional GPS network. http://www.ga.gov.au/geodesy/argn/. Accessed 16 May 2009

Goncalves RM (2010) Short-term trend modeling of the shoreline through geodetic data using linear regression, robust estimation and artificial neural networks. Ph.D. thesis, geodetic sciences post-graduate program. Federal University of Parana (UFPR), Curitiba, p 152

Goncalves RM, Awange JL, Krueger CP, Heck B, Coelho LS (2012) A comparison between three short-term shoreline prediction models. Ocean Coast Manag 69:102–110.doi:10.1016/j.ocecoaman.2012.07.024

Hammond WC, Brooks BA, Bürgmann R, Heaton T, Jackson M, Lowry AR, Anandakrishnan S (2010) The scientific value of high-rate, low-latency GPS data, a white paper

Hammond WC, Brooks BA, Bürgmann R, Heaton T, Jackson M, Lowry AR, Anandakrishnan S (2011) Scientific value of real-time global positioning system data. Eos 92(15):125–126. doi:10.1029/2011EO150001

Hofman-Wellenhof B, Lichtenegger H, Wasle E (2008) GNSS global navigation satellite system: GPS GLONASS; Galileo and more. Springer, Wien

IGS (2009) International GNSS service. http://igscb.jpl.nasa.gov/. Accessed 16 May 2009

Leick A (2004) GPS satellite surveying, 3rd edn. Wiley, New York

Luhmann T, Robson S, Kyle S, Harley I (2011) Close range photogrammetry: principles, techniques and applications. whittles publishing, Scotland

Maryam D, Zoej V, Javad M, Iman E, Ali M, Sassan S (2009) InSAR monitoring of progressive land subsidence in Neyshabour, northeast Iran. Geophys J Int doi:10.1111/j.1365-246X.2009.04135.x

Matsuzaka S (2006) GPS network experience in japan and its usefulness. In: Proceedings of 17th United Nations regional cartographic conference. Geographical Survey Institute, Bangkok Thailand

Moffit FH, Mikhail E (1980) Photogrammetry, 3rd edn. Harper and Row Publishers, NY

Motagh M, Djamour Y, Walter TR, Wetze H, Zschau J, Arabi S (2007) Land subsidence in Mashhad Valley, northeast Iran: results from InSAR, levelling and GPS. Geophys J Int 168:518–526. doi:10.1111/j.1365-246X.2006.03246.x

Murai S (1999) GIS Work Book: Fundamental and Technical courses. vols 1–2. National Space Development Agency. of Japan (NASDA)/Remote Sensing Technology Center of Japan (RESTEC). Japan Association of surveyors

National Geodetic Survey (2006) Guidelines for New and Existing Continuously Operating Reference Stations (CORS). NOAA, Silver Spring, MD

Prasad R, Ruggieri M (2005) Applied satellite navigation using GPS, GALILEO and Augmentation Systems. Artech House, Boston

Rizos C (2001) Alternatives to current GPS-RTK services and some implications for CORS infrastructure and operations. GPS Sol 11(3):151–158

Sagiya T (2005) A decade of GEONET: 1994–2003 The continuous GPS observation in Japan and its impact on earthquake studies Earth Planets Space (56): xxix-xli

SAPOS (2009) Satellitenpositionierungsdienst der deutschen Landesvermessung. http://www.sapos.de/. Accessed 16 May 2009

Schenk T (2005) Introduction to photogrammetry. The Ohio State University, Columbus

Schofield W, Breach M (2007) Engineering Surveying, 6th edn. Elsevier, Amsterdam

Snay R, Soler T (2008) Continuously operating reference station (CORS): History, applications, and future enhancements. J Surv Eng 134(4):95–104. doi:10.1061/(ASCE)0733-9453(2008)134:4(95)

Stone W (2006) The evolution of the national geodetic survey's continuously operating reference station network and online positioning user service. http://www.ngs.noaa.gov/PUBS_LIB/Evolution_of_CORS_and_OPUS.pdf. Accessed 16 May 2009

US Army Corps of Engineers (2007) NAVSTAR global positioning system surveying. Engineering and Design Manual, EM 1110-1-1003

Wallace N (2007) CORS simulation for Australia. Curtin University of Technology, Final year project (unpublished)

Wolf P (1980) Elements of photogrammetry. McGraw Hill Book Co., NY

Wolfgang D (2005) Funktion und Nutzung des SAPOS—Deutschland-Netzes, Flächenmanagement und Bodenordnung (FuB). http://www.sapos.de/pdf/SAPOS_Deutschland_Netz_klein.pdf. Accessed 16 May 2009

Chapter 10
Photogrammetry

A map is the greatest of all epic poems. Its lines and colors show the realization of great dreams

—Gilbert H. Grosvenor, Editor, National Geographic (1903–1954).

10.1 Definition and Scope

Like in many other disciplines, there is no universally accepted definition of the term *photogrammetry*. The Manual of Photogrammetry (2003) defines photogrammetry as the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of electromagnetic (EM) radiant energy and other phenomena. Notably, the extracted information could be of a geometric, physical, semantic or even temporal nature, although in many photogrammetric applications the geometric information is more relevant. Other popular definitions of this non-contact discipline are given e.g., in Moffit and Mikhail (1980), Wolf (1980), Kraus (1994), Schenk (2005), etc. In a very broad sense, and from a network design point of view, Fraser (2000) reckons that a photogrammetric system is one that meets the following basic requirements;

- capability for self diagnosis (quality control),
- potential for high precision and reliability (redundant sensor data), and
- task flexibility with respect to 3D object reconstruction functions.

The term *photogrammetry* is developed from the Greek words *phos* or *phot*, which refers to *light*, *gramma*, which means *letter* or something *drawn*, and *metrein*, the noun of *measure*. Strictly speaking, photogrammetry may be considered to be a subset of remote sensing (see Chap. 11) with photogrammetry zeroing in only on the visible part of the EM spectrum, while remote sensing focuses on the entire EM spectrum (see Sect. 11.1). In practice, however, photogrammetry has often been treated and

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viewed as a distinct and separate discipline away from remote sensing. The main reason for this perception is ostensibly because photogrammetry developed much earlier than remote sensing. In general, both photogrammetry and remote sensing provide Geographic Information Systems (GIS) with essential geospatial data and information. As a matter of fact, the core topographic information in most GIS databases and Spatial Data Infrastructures (SDIs) today is still essentially produced through photogrammetric procedures.

Depending largely on the type of application, as well as, to some extent, on variables such as the platform and/or sensor types employed, different types of photogrammetry can be distinguished including; aerial photogrammetry, such as the one used for aerial mapping of Stirling Natural Environment Coastcare (SNEC) in Western Australia (see e.g., Sect. 18.1), terrestrial and close-range photogrammetry, biostereometrics, industrial photogrammetry, architectural photogrammetry, etc. Terrestrial and close-range photogrammetry was the first type of photogrammetry practiced, and even though it has in recent years re-emerged in prominence, in common parlance the term photogrammetry often refers to aerial photogrammetry.

Historically, photogrammetry is a fairly old discipline with the term "photogrammetry" first coined by *Meydenbauer* in 1893. During the early phase of its development, photogrammetry was limited in applications, focusing largely on terrestrial surveys of inaccessible objects like mountains, expeditions, glaciers, buildings, etc. Over the years, however, a paradigm shift has occurred in photogrammetry resulting from developments in computing and imaging technologies. This has fundamentally changed the way photogrammetric procedures are implemented from the traditional *plane table photogrammetry* into *analogue photogrammetry*, through *analytical photogrammetry*, and more recently, into *digital (softcopy) photogrammetry* as illustrated in Fig. 10.1. The net effect of this paradigm shift has been improved accuracy and reliability in map restitution. In Table 10.4 (p. 227) is presented a summary of the basic differences between each of these different phases of photogrammetry.

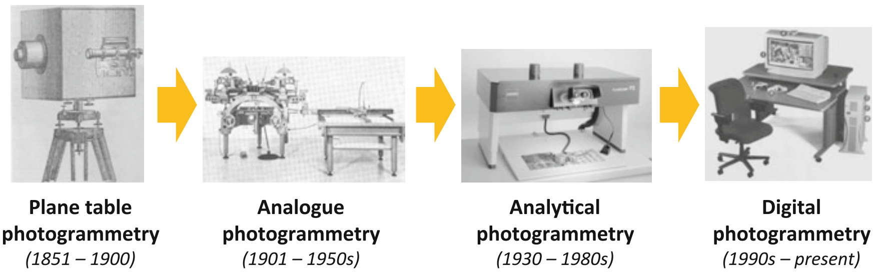

Fig. 10.1 Paradigm shift in photogrammetry

10.2 Geometry of Aerial Photography

10.2.1 Central Perspective Projection

In principle, an aerial photograph is imaged on the basis of the *central perspective projection* as shown in Fig. 10.2. This also helps to define the spatial relationship between the image and object spaces. According to the central perspective projection, the object point, perspective center, and corresponding image point all lie on a straight line.

The central perspective projection is defined mathematically through the *collinearity condition equations* described through Eqs. 10.1 and 10.2. These are apparently the most important equations in photogrammetry.

$$x_p = -c\frac{r_{11}(X_p - X_o) + r_{12}(Y_p - Y_o) + r_{13}(Z_p - Z_o)}{r_{31}(X_p - X_o) + r_{32}(Y_p - Y_o) + r_{33}(Z_p - Z_o)} \tag{10.1}$$

$$y_p = -c\frac{r_{21}(X_p - X_o) + r_{22}(Y_p - Y_o) + r_{23}(Z_p - Z_o)}{r_{31}(X_p - X_o) + r_{32}(Y_p - Y_o) + r_{33}(Z_p - Z_o)}, \tag{10.2}$$

where (x_p, y_p) represent the coordinates of the image point (p) (usually corrected for systematic errors); c is the calibrated focal length; r_{ij} for $i, j = 1, 2, 3$ are the elements of the orthogonal rotation matrix comprising the three angles (ω, ϕ, κ); (X_o, Y_o, Z_o) are the coordinates of the perspective center and (X_p, Y_p, Z_p) the coordinates of the object point (P).

The six parameters $(\omega, \phi, \kappa, X_o, Y_o, Z_o)$ constitute the elements of *exterior orientation*, which define the position and attitude of the camera in space. For a single camera, they are conventionally estimated through the process of *space resection*

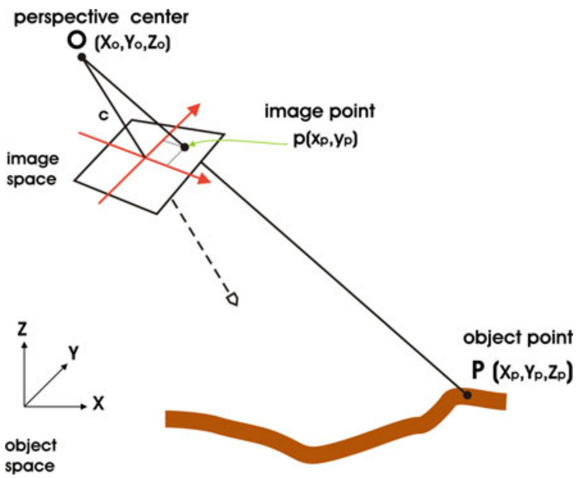

Fig. 10.2 Principle of central perspective projection

provided that sufficient control points are available. Once the elements of exterior orientation are determined, every measured image point contributes two collinearity equations while adding three unknown parameters, namely the coordinates of the object point (X_p, Y_p, Z_p).

Solving for the coordinates of the object point requires that for the same image point, two conjugate points are imaged on corresponding overlapping aerial photographs, otherwise known as *stereopairs*. Therefore, a minimum of a stereopair is required for successful *intersection* of an object point. This provides for stereoscopy in photogrammetry and is particularly critical in the perception of depth and estimation of heights by measuring *stereoscopic parallax*. Since the collinearity equations are nonlinear, solving for all the above parameters requires that these equations be first linearized using Taylor's series.

10.2.2 Photographic Scale

The level of information detail that can be extracted from an aerial photograph depends largely on the photographic scale. The photographic scale also has a direct influence on the final map scale and hence the application to which aerial photographs (or even maps) can be put to. For a particular aerial camera, the photographic scale varies depending on the flying height as well as the degree of relief variation. Thus, more hilly terrain will exhibit higher photographic scale variation than fairly level ground. Tilt displacement can also influence scale variation, especially if the amount of tilt is significant. Procedures for solving these equations without linearization are presented, e.g., in Awange et al. (2010), Awange and Grafarend (2005).

As shown in Fig. 10.3 the scale of a near vertical photograph can be approximated using Eq. 10.3.

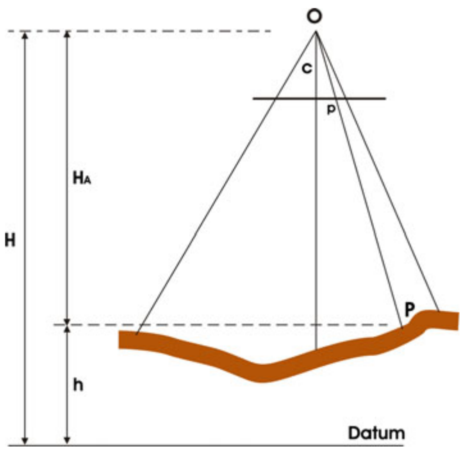

Fig. 10.3 Photographic scale

$$s = \frac{c}{H_A} = \frac{c}{H - h}, \tag{10.3}$$

where s is the photographic scale, c is the calibrated focal length, H is the flying height above datum, h is the average terrain elevation and H_A is the flying height above average terrain.

10.2.3 Classification of Aerial Photographs

As mentioned in Sect. 10.2.2, on the basis of photographic scale alone, different types of aerial photographs can be distinguished as being better suited for different types of applications than others. In general, therefore, it is important to classify aerial photographs accordingly. By convention, these are classified on the basis of several factors including; the orientation of the camera axis, the focal length of the camera, and the type of the emulsion. Using orientation one can differentiate between:

(1) True vertical photograph: This is a photograph taken with the camera axis perfectly vertical. Such photographs hardly exist in reality.
(2) Near vertical photograph: A photograph acquired with the camera axis nearly vertical. The deviation from the vertical is called *tilt*. For a near vertical photograph the amount of tilt should not exceed 3°.
(3) Oblique photograph: A photograph taken with the camera axis intentionally tilted between the vertical and horizontal. A high oblique photograph is tilted so much that the horizon is imaged on the photograph, while a low oblique photograph does not include the horizon.

Whereas vertical photographs are employed in diverse photogrammetric applications, their oblique equivalents are used largely for interpretation work and to deliver *bird's eye views*. The angular coverage is a function of focal length and format size. Standard focal lengths and associated angular coverages are summarized in Table 10.1. While wide angle cameras are the most popular in most photogrammetric mapping applications, super wide angle cameras are used in flat regions. On the other extreme end, narrow angle cameras are used in reconnaissance and intelligence work.

The sensitivity range of emulsion can be used to classify photography into:

(a) Panchromatic black and white: This is the most widely used type of emulsion for photogrammetric mapping.
(b) Color: This is mainly used for interpretation purposes. However, color is increasingly being used for mapping applications.
(c) Infrared black and white: Since infrared is less affected by haze it is used in applications where weather conditions may not be as favorable for mapping missions (e.g., intelligence).
(d) False color: This is particular useful for interpretation, mainly for studying vegetation (e.g., crop disease) and water pollution.

Table 10.1 Classification of aerial photographs based on angular coverage

	Super wide angle	Wide angle	Intermediate angle	Normal angle	Narrow angle
Focal length (mm)	88	153	210	305	610
Instantaneous field of view (IFOV)	119	82	64	46	24
Photographic scale	7.2	4.0	2.9	2.0	1.0
Ground coverage	50.4	15.5	8.3	3.9	1.0

Source Schenk (2005)

10.3 Photogrammetric Procedures

There are different ways of trying to understand the basic photogrammetric procedure. From a system's perspective, one can look at this as comprising of the three interrelated phases of data acquisition, photogrammetric restitution, and photogrammetric output as illustrated in Fig. 10.4. Further discussions in this Chapter will be made on the basis of this distinction.

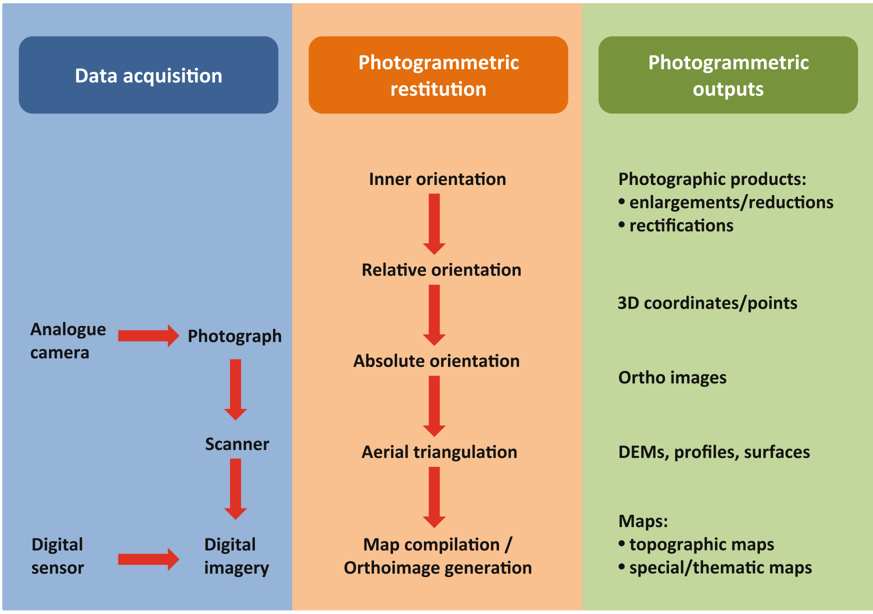

Fig. 10.4 Basic photogrammetric procedure. Modified after Schenk (2005)

10.3.1 Data Acquisition

10.3.1.1 General Remarks

Although there are different types of cameras designed specifically for use with ground-based and space-based platforms, the discussion hereafter only focuses on airborne-based sensors. The aerial camera is the principle data acquisition tool (sensor) in photogrammetry. It is focused at infinity so that objects on the ground beneath are imaged at a distance equal to the focal length of the taking camera. Today, both analogue frame cameras using film based imaging systems and digital aerial cameras employing charged-couple devices (CCD) are used in photogrammetric data acquisition. As shown in Fig. 10.4, although imagery acquired from analogue cameras need to be first scanned to get these into digital format, digital sensors allow imagery to be directly obtained in digital format ready for processing within a digital environment.

In general, the lens employed in aerial cameras has exceptionally high geometric fidelity. However, it is still imperfect and fails to perfectly replicate the central perspective projection, realizing in practice only an approximation of the same. Hence, there is need to correct resulting aerial imagery for systematic errors incurred during the process of data acquisition, such as tilt and relief displacements, scale variation and film distortion for analogue cameras. In order to procure photography that meets the expected mapping specifications, there is need to carry out a priori photogrammetric project planning as discussed in Sect. 10.3.1.4.

10.3.1.2 Analogue Frame Camera

The most popular type of analogue camera employed in aerial photogrammetry is the frame camera. This is basically a metric sensor that operates by freezing/capturing a square area on the ground in one instance of time when an exposure is made. It normally uses a standard format size of 23 cm $\times$ 23 cm. Analogue frame cameras employ film-based systems, which means that the exposed film needs to be processed to develop the photographs once the images are acquired.

The high imaging accuracy of analogue frame cameras is realized through the use of a lens of high geometric fidelity with minimum lens distortion, and the employment of a film flattening device to ensure that the film is held flat against the camera focal plane at the instance of exposure. Camera accessories are also incorporated to ensure proper functioning of the entire analogue sensor. Details of the components of frame analogue cameras are given in Manual of Photogrammetry (2003), Moffit and Mikhail (1980).

10.3.1.3 Digital Aerial Cameras

Compared to the long distinguished history of successful mapping applications using analogue frame cameras dating back from around the 1920s, digital aerial cameras have been in operation for a much shorter period of time from just around the year 2000. The basic difference between these two types of sensors is that digital cameras employ CCDs and no film. In principle, the CCD works by converting photons, which fall onto the sensor surface into electrons. These are accumulated in capacitors and converted into digital form for output. Details of this operation are given in most reference books on digital photogrammetry (see e.g., Mikhail et al. 2001; Lindner 2003, etc.).

From a geometric point of view, digital sensors exhibit larger lens distortions and medium accuracy compared to their analogue counterparts and are only stable after warming up. They are of medium resolution compared to silver emulsions employed in analogue cameras. One can distinguish between linear arrays used primarily for satellite or airborne sensors and 2D arrays employed in close range photogrammetric work. Ultimately, the two most important characteristics for digital sensors applicable in photogrammetry are the size of the array and the pixel size. Other important features include the dynamic range, the geometric characteristics (particularly the lens distortion), the transfer of data from the sensor to storage and the time taken to record an image.

During the last decade, competition has been witnessed in the development of digital aerial cameras with single and multiple frame sensors, as well as three-line scanners (TLS) and multiple line scanners. Table 10.2 gives the characteristics of several digital aerial frame cameras including the DMC,[1] UltraCam,[2] DSS[3] and DIMAC[4] sensors, which are further illustrated in Fig. 10.5. Similarly, examples of digital line scanners comprising the Leica ADS40,[5] Startlabo StarImager[6] and JAS 150[7] are given in Table 10.3, with Fig. 10.6 showing the operating principle of the Leica ADS40 camera.

10.3.1.4 Photogrammetric Project Planning

Planning for a photogrammetric project is the first critical and essential step to consider before execution of aerial photography. Given the area that needs to be mapped, and following a user needs assessment, the photogrammetrist, in consultation with the client, must define the various project parameters, such as overlap and sidelap

[1] http://www.intergraph.com.

[2] http://www.microsoft.com/ultracam.

[3] http://www.applanix.com.

[4] http://www.dimacsystems.com.

[5] http://www.leica-geosystems.com.

[6] http://www.starlabo.co.jp.

[7] http://www.jenoptik.com.

Table 10.2 Digital aerial frame cameras

Digital aerial frame camera type	Pixels	Pixel size (μm)	Focal length (mm)
Intergraph DMC	8,000 × 14,000 pan	12	120
Excel UltraCam$_D$	7,500 × 11,500 pan	9	100
Applanix DSS	4,092 × 4,077	9	55 or 35
DIMAC	up to 4 times 8,984 × 6,732	9	47–210

Fig. 10.5 Digital aerial frame cameras

Table 10.3 Digital aerial line scan cameras

Digital aerial line scan camera type	Pixels	Pixel size (μm)	View direction in flight direction	Field of view across
Leica ADS40	2 × 12,000 staggered	6.5	−16°, nadir, 26°	62°
Starlabo starImager	14,400	5	−23°, nadir, 17°	62°
JAS 150	12,000	6.5	nadir, ± 12°, ± 20.5°	29°

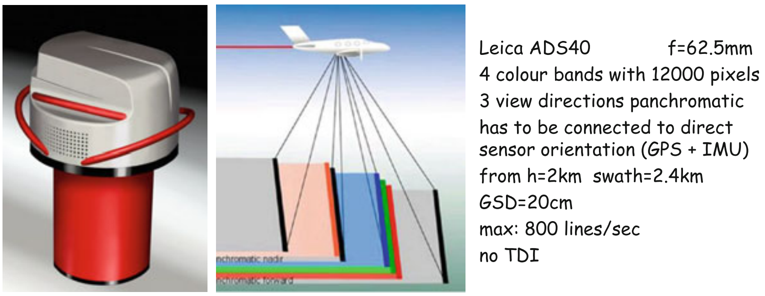

Fig. 10.6 Operating principle of Leica ADS40. *Source* www.leica-geosystems.com

requirements, photographic scale, final map scale, instruments to be used etc. These parameters inform the data acquisition, photogrammetric restitution and map compilation procedures that need to be employed.

Basically, photogrammetric project planning consists of three interrelated phases, namely;

(a) Development of a *flight plan* which must be followed when taking the aerial photographs to be used in the project. The flight lines to be used during the photography are first drawn on a topographic map. This is done with the objective of avoiding gaps in the resultant photography, and taking into account factors like the overlap and sidelap requirements, general orientation of the area to be mapped, etc.
(b) Planning the *ground control* and executing the necessary field surveys to satisfy the accuracy requirements of the project. Photo control is required in photogrammetric restitution. Suitable, sufficient and adequately distributed ground control points whose images clearly appear on the resultant photographs need to be premarked or postmarked and coordinated appropriately using, e.g., GNSS discussed in Chap. 9.
(c) Estimating the *costs* involved in the project. Aerial photogrammetry can be fairly expensive and an appropriate budget needs to be provided for the exercise to be successful.

Details of typical computations in photogrammetric project planning are discussed e.g., in Manual of Photogrammetry (2003), Moffit and Mikhail (1980), Wolf (1980), etc. Example 10.1 demonstrates a typical example of photogrammetric project planning.

Example 10.1 (*Photogrammetric project planning* (*Source*: Konecny 2003))
The following is an example on how to quickly estimate the number of photographs required to cover an area to be mapped through photogrammetry. Figure 10.7 shows a typical photogrammetric data acquisition schema. The ground distance between the two exposure centers designated as b is given by:

$$b = a\left(1 - \frac{o}{100}\right), \tag{10.4}$$

where o is the overlap and a is the ground format coverage for an image. For a typical overlap of 60 % the ground distance b is given by:

$$b = a(0.4). \tag{10.5}$$

If the sidelap between the strips p is 30 %, then the ground distance between any two adjacent strips, q, becomes:

$$q = a\left(1 - \frac{p}{100}\right) = a(0.7). \tag{10.6}$$

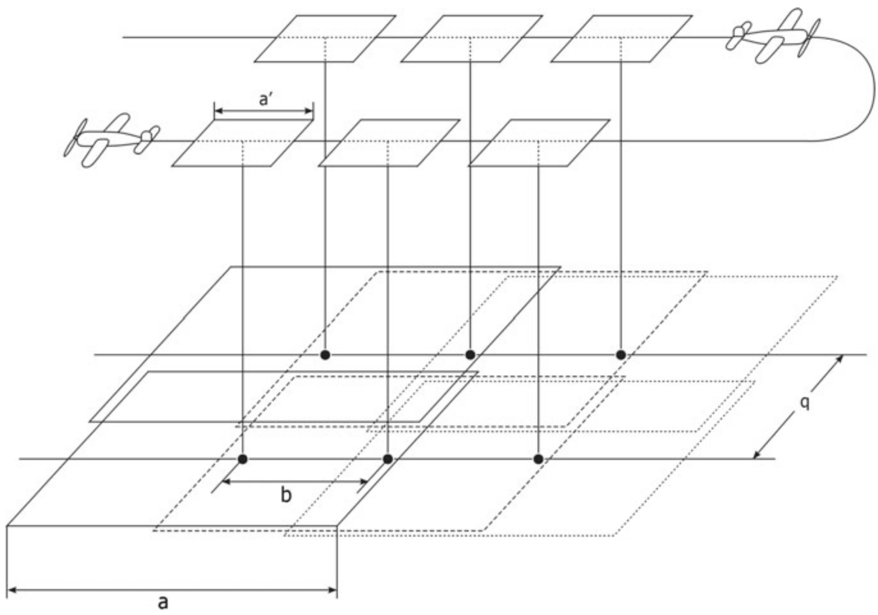

Fig. 10.7 Photogrammetric data acquisition configuration

To calculate the number of photographs required for the entire area it is important to first consider a single model comprising of two overlapping photographs. The net (overlap) area, N, has the dimensions $N = b \cdot q$. Thus, the number of photographs, n, required to cover a total area, B, can be estimated from:

$$n = \frac{B}{N}. \tag{10.7}$$

♣ End of Example 10.1

10.3.2 Photogrammetric Restitution

As described in Sect. 10.1, the basic objective of photogrammetry is to extract useful geometric and other information types by analyzing and interpreting photographic imagery. It therefore follows that once the aerial photographs have been acquired they need to be further analyzed and interpreted to extract 3D geoinformation from the iconic 2D imagery. Traditionally, this has been achieved through the process of *photogrammetric restitution* as illustrated in Fig. 10.8. Conceptually, this involves simulation and inversion of the basic photographic process and can be implemented using either plane table-, analogue-, analytical- or digital photogrammetric

Fig. 10.8 Classical photogrammetric workflow

techniques. Table 10.4 compares the characteristics of these different approaches towards photogrammetric restitution.

The following subsections discuss the different stages in photogrammetric restitution that define the basic photogrammetric workflow. The focus here is only on conceptual ideas and not on implementation issues.

10.3.2.1 Interior Orientation

The main objective of *interior orientation* is to reconstruct the same geometry (or bundle of rays) that existed during image acquisition. In principle, therefore, this endeavors to simulate the photographic process. The elements of interior orientation are conventionally estimated through *camera calibration*. The magnitude and sense of these parameters give an indication by how much the geometry of image formation in the employed camera deviates from a perfect central perspective projection (described in Sect. 10.2.1). The main cause for this deviation is the various systematic errors that are likely to have occurred during image acquisition, including tilt and relief displacements, along with scale variations, film distortions, etc. This calls for appropriate mathematical models to be adopted to correct for these error sources.

The interior orientation parameters estimated through camera calibration include: coordinates of the principal point (x_o, y_o), the calibrated focal length (c), radial lens and tangential lens distortion elements, film deformation, atmospheric refraction, and earth curvature. The purpose of correcting the image rays for these errors is to ensure that the line from the object space passing through the perspective center to the image space is a straight line, thus fulfilling one of the basic assumption of collinearity condition given in Eqs. 10.1 and 10.2 (p. 217). In addition, it is also

Table 10.4 Comparison of various photogrammetric restitution methods

Characteristic	Description
Plane table photogrammetry	
Methodology	Derivation of angles from image points
Users	Surveyors
Auxiliary disciplines	Photography; descriptive geometry; projective geometry; perspective geometry
Origins	da Vinci—basic geometry (c. 1480); Desargues—projective geometry (c. 1625); Lambert—perspective geometry (1759); Daguerre—silver emulsions and photographic exposure (1839); Meydenbauer—photogrammetry terminology coined (1893)
Practical uses	Sebastian Finsterwalder mapping Vernagt Glacier (1888); Lavssedat mapping Paris from rooftops (1851)
Application	Limited to terrestrial surveys of inaccessible objects (e.g., mountains, expeditions, glaciers, buildings)
Analogue photogrammetry	
Methodology	Reconstruction of stereo-models by optical or mechanical instruments
Users	Photogrammetrists
Auxiliary disciplines	Optics, mechanical tooling, stereoscopy
Origins	Pulfrich—stereocomparator (1901); von Orel—autograph (1907); Gasser plotter—Multiplex (1915)
Practical uses	Stereoplotters by Leica (Wild), Zeiss etc. (1926)
Application	Topographic Mapping (1939–1945); accelerated mapping programs in the 1950s
Analytical photogrammetry	
Methodology	Integration of computers in stereo restitution
Users	Photogrammetrists
Auxiliary disciplines	Analytical geometry, matrix algebra, least squares adjustment
Origins	Collinearity equations (Gast, 1930); bundle block adjustment (H. Schmid, 1953); analytical plotter (U. Helava, 1957); orthocomp by Zeiss (1980)
Practical uses	Semiautomatic orientation; DEM; analytical aerial triangulation; vector plotting
Application	Improved accuracy and reliability in map restitution
Digital photogrammetry	
Methodology	Use of scanned analogue images or digital images in pixel format
Users	Geoinformatics specialists
Auxiliary disciplines	Computer science, digital image processing
Origins	Optronics—1970; stereo workstation—1988; digital image matching (Sharp—1965)
Practical uses	Digital orthophotos, space imagery restitution
Application	Integration into GIS

Modified after Konecny (2003)

usually important to evaluate the resolution of the entire imaging system through an assessment of the *modulation transfer function* (MTF).

10.3.2.2 Relative Orientation

Relative orientation is the process that follows after inner orientation. The basic objective of relative orientation is to constrain corresponding conjugate rays to ensure that they intersect uniquely in space in order to form a stereomodel. In essence, this attempts to reverse the photographic process by ensuring that the same relative position that the two overlapping images exhibited during image acquisition is maintained. This is realized in practice by removing parallax around six standard locations, otherwise referred as the *von Gruber* locations, defined within the overlap area (see Fig. 10.9, p. 228). The procedure adopted in the removal of parallax will vary depending on the photogrammetric restitution method applied.

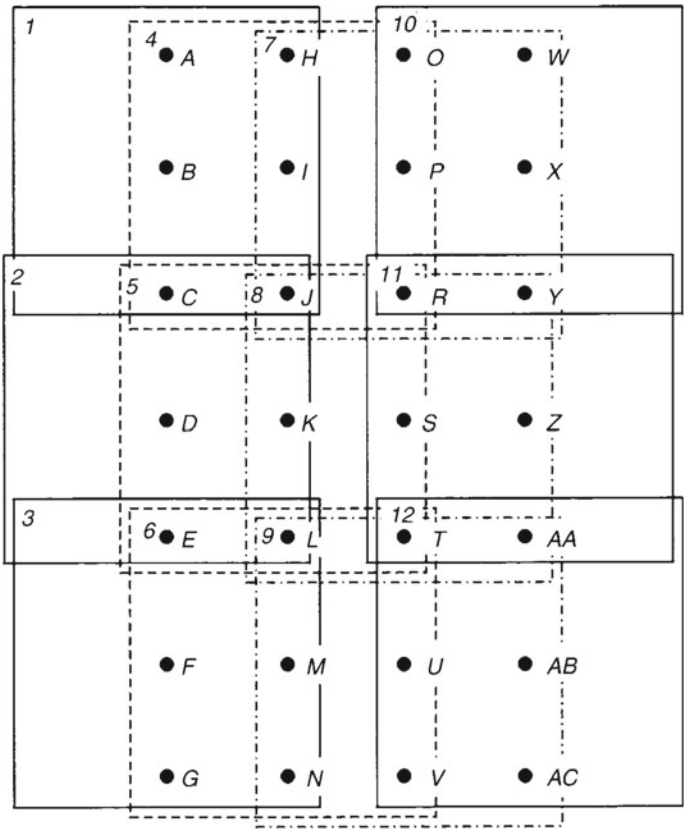

Fig. 10.9 A schematic of a block of aerial photography showing the *von Gruber* location of various control points. These points can be coordinated using GNSS techniques to allow for aerial triangulation

Table 10.5 Stereoscopic viewing methods

Dimension	Stereoscopic implementation
Spatial	2 monitors + stereoscope
	1 monitor + stereoscope (split screen)
	2 monitors + polarization
Spectral	Anaglyphic
	Polarization
Temporal	Stereo alternate synchronization by polarization

Source Schenk (2005)

Once parallax has been successfully removed a 3D *stereomodel* that is a scaled replica of the imaged ground underneath is generated. This stereomodel can be viewed *stereoscopically* and even measured. To successfully view the stereomodel, an appropriate viewing (ocular) system that delimits the left eye to view only the left stereopair, and the right eye to view only the right stereopair needs to be in place. Reversing the viewing system results in a *pseudoscopic* view, in which case hills appear as valleys and vice-versa. In principle, stereoscopic viewing can be implemented in different ways as summarized in Table 10.5.

10.3.2.3 Absolute Orientation

The created stereomodel has an arbitrary scale and is not anchored on any existing datum. To overcome both the scale and height datum defects requires that the stereomodel be appropriately scaled and leveled. This is achieved through the use of existing ground controls measured using GNSS during the process of *absolute orientation*. The scaled and leveled stereomodel can then be used in the compilation of maps and production of orthoimages.

10.3.2.4 Aerial Triangulation

After successful relative orientation a stereomodel will be produced from a minimum of every stereopair employed. For a photogrammetric block comprising of several stereopairs, it is necessary to relate multiple stereo images to each other so as to link and connect them up. This is achieved by employing the collinearity model described in Sect. 10.2.1, and using sufficient tie, pass and control points, as shown in Fig. 10.9, in a process referred to as *aerial triangulation* or *aerotriangulation* that seeks to;

(1) determine the complete exterior orientation parameters of each image in the photogrammetric block that includes the (X_o, Y_o, Z_o) coordinates of the position of the camera in space, as well as the camera attitude (defined through the rotations ω, ϕ, κ), and
(2) estimate ground coordinates (X, Y, Z) of measured conjugate image points.

The collinearity model can be expanded further to incorporate additional parameters, especially those required to model various systematic error sources, such as radial and tangential lens distortions. In view of the numerous image points that need to be processed and the substantial number of unknown parameters that need to be estimated, to enhance the reliability of the estimation process, a *bundle adjustment* approach is usually adopted in most practical photogrammetric triangulation. This allows for the simultaneous estimation of all unknown object space coordinates, together with the elements of interior and exterior orientation from the measured image coordinates and provided photogrammetric control within one common bundle adjustment solution. The least squares bundle adjustment solution is particularly attractive because it significantly improves the reliability of the estimation given the high degree of freedom encompassed.

10.3.3 Photogrammetric Output and Use in EnvPM

Photogrammetric products fall generally into three categories, namely; photographic products, computational results and maps. Photographic products are essentially derivatives of single photographs or composites obtained from stereopairs. Supposing that an analogue camera is used, during the exposure of the film a latent image is formed which can be developed into a *negative*. Similarly, *diapositives* and *paper prints* can also be produced (see Fig. 10.10). In addition, *enlargements* may also be obtained to support preliminary design or planning of an EPM project (e.g., flood management, wetland rehabilitation, etc.).

All the above products are derived from unrectified photographs. Better approximations to a map are *rectifications* that are aerial photographs corrected for tilt displacement. The rectified photographs can be further processed to correct for relief displacement through the process of *differential rectification*. This results in an *orthoimage* that is geometrically identical to a map. Composites are frequently

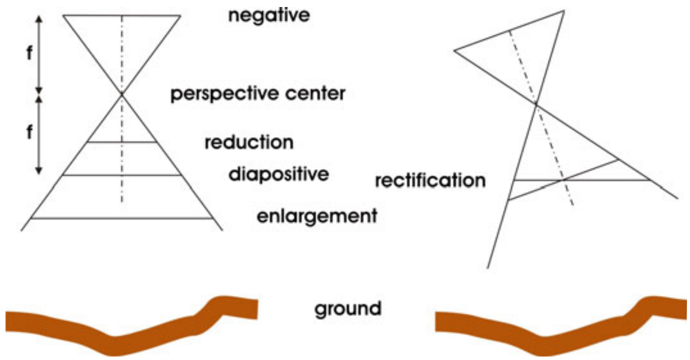

Fig. 10.10 Typical photographic products. *Source* Schenk (2005)

used as a first base for general planning studies. *Photomosaics* are probably the most common composites, but composites derived from orthophotos, called *orthophoto maps* are increasingly being applied. Such photogrammetric products find use in EPM, e.g., in soil landscape mapping.

For computational results, *aerial triangulation* represents a very successful application of photogrammetry that delivers 3D positions of points measured on photographs in a ground coordinate system. *Profiles* and *cross-sections* are typical products in the design of highways from which earthwork quantities are computed. The most popular form for representing height variations of the earth's surface is the *DEM/DTM* (Digital Elevation Model/Digital Terrain Model). For EPM, this is useful for projects that monitor spatial changes, e.g., management of earthquake events, tsunamis, etc.

Ultimately, however, *maps* remain the most prominent product of photogrammetry. They can be produced at various scales and degrees of accuracies depending on the desired EPM mapping application. Unlike aerial photographs that exhibit a central perspective projection, maps are generally produced using an orthographic projection. Planimetric maps contain only the horizontal position of ground features, while topographic maps include elevation data, usually in the form of contour lines and spot elevations. On the other hand, thematic maps emphasize one particular theme e.g., transportation network, geology etc. Details of different types of maps are discussed in Awange (2012), Awange and Kiema (2013).

10.4 Concluding Remarks

It is indisputable that photogrammetry has come a long way indeed. In terms of data acquisition, it has transited from the early days, when pigeons were used as platforms for cameras, to the modern era, where digital sensors are employed to acquire image data directly in digital format. With regard to image restitution, photogrammetry has gone through a complete paradigm shift. From the era of plane table photogrammetry, when terrestrial and close range mapping systems were employed to map inaccessible features, to the present time, when digital (softcopy) photogrammetry has come of age. In terms of output, photogrammetry has moved from the era of traditional topographic maps, that were difficult and expensive to revise, to the modern era, where orthophotos can be economically applied to update GIS and CAD data. the next chapter provides insight on how this can be achieved.

Against the above background, it seems reasonable to pose the question; what does the future portend for photogrammetry? This is a very difficult question to answer, even for an optimist. The truth is that photogrammetry today faces, perhaps, its most serious challenge ever as a mapping tool. For instance, compared to LiDAR, photogrammetry is disadvantaged in several ways, especially in terms of flexibility, cost and delivery times. Nonetheless, as of now, photogrammetry still remains fairly competitive, particularly with regard to accuracy and reliability. However, to effectively compete with other non-contact mapping technologies, photogrammetry will need to be more competitive, specifically in terms of cost and delivery times.

References

Awange JL, Grafarend EW, Palancz B, Zaletnyik P (2010) Algebraic geodesy and geoinformatics. Springer, Berlin

Awange JL, Grafarend EW (2005) Solving algebraic computational problems in geodesy and geoinformatics. Springer, Berlin

Awange JL (2012) Environmental monitoring using GNSS. Springer, Berlin

Awange JL, Kiema JBK (2013) Environmental geoinformatics, monitoring and management, Springer, Berlin. Solving algebraic computational problems in geodesy and geoinformatics, Springer, Berlin

Fraser CS (2000) Network design. In: Atkinson KB (ed) Close range photogrammetry and machine vision. Whittles Publishing, Scotland

Konecny G (2003) Geoinformation: remote sensing, photogrammetry, geographic information systems. Taylor and Francis, London

Kraus K (1994) Photogrammetry, Verd. Duemmler Verlag, Bonn

Lindner W (2003) Digital photogrammetry: theory and applications. Springer, Berlin

Manual of Photogrammetry (2003) In: McGlone C, Mikhail E, Bethel J (eds) 5th edn, American society of photogrammetry and remote sensing, Bethesda

Mikhail EM, Bethel JS, McGlone JS (2001) Introduction to modern photogrammetry. Wiley, New York

Moffit FH, Mikhail E (1980) Photogrammetry, 3rd edn. Harper and Row Publishers, New York

Schenk T (2005) Introduction to Photogrammetry. The Ohio State University, Columbus

Wolf P (1980) Elements of photogrammetry. McGraw Hill Book Co, New York

Chapter 11
Remote Sensing

Know the weather, know the terrain, and your victory will be complete

—Sun Tzu (500 BC)

11.1 Basic Concept

Remote sensing is defined as the art, science and technology through which the characteristics of object features/targets either on, above or even below the earth's surface are identified, measured, and analyzed without direct contact existing between the sensors and the targets or events being observed, see e.g., Jensen (2009), Lillesand et al. (2010), Richards (1994), Murai (1999), etc. This allows for *information* about such object features to be obtained by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information.

Electromagnetic radiation is normally used as the *information carrier* in remote sensing. Such electromagnetic radiation that is either reflected or emitted from targets normally constitutes remote sensing data. This can be detected by a sensor usually on-board airborne (e.g., aircraft or balloon) or space-borne (e.g., satellites and space shuttles) platforms. A comprehensive survey of airborne and space-borne missions and sensors for observing the earth is given in Kramer (2002). As an analogy, of the five basic human senses, three of them namely; sight, hearing, and smell may be considered forms of "remote sensing", where the source of information is at some distance away from the sensors, in this case the eyes, ears and nose respectively. In contrast, however, the other two human senses (i.e., taste and touch) rely on direct physical contact with the source of information.

As shown in Fig. 11.1, the process of remote sensing is characterized by various stages and interactions summarized as follows: (a) an energy source or illumination is used to provide electromagnetic energy to the target of interest, (b) interactions between the electromagnetic radiation and the atmosphere, (c) interaction between the target and the electromagnetic radiation, (d) re-transmission through

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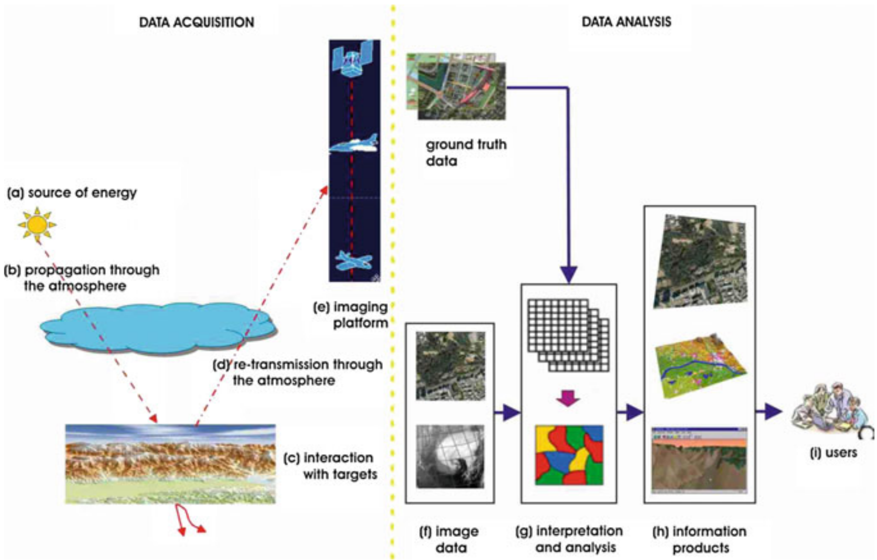

Fig. 11.1 Remote sensing process

the atmosphere, (e) recording of reflected and emitted energy from the target by the sensor, (f) transmission, reception and processing of recorded energy into an image, (g) interpretation and analysis of image to extract desired information and (h/i) application of the information about the object or target in order to better understand it, reveal some new information, or assist in solving a particular problem. An example of practical application of remote sensing is the pollution assessment of land-use, creeks, mangroves and water bodies in Ogoniland, River State of Nigeria (see Sect. 19.1.3.2), p. 390.

Although it is now possible to expand the object feature base in image interpretation beyond the traditional spectral domain to include spatial and other dimensions, the practice of remote sensing still relies heavily on the spectral characteristics of objects. Accordingly, each object has a unique spectral signature of reflection or emission dependent on the sun, climate, atmosphere, ground condition, sensor among other factors. This allows the discrimination of the object *type*, *class*, *rank* or *density* to be made through image processing and analysis as illustrated in Fig. 11.2.

Even though the invention of classical photography can be traced way back to around 1860 and balloon photography was pioneered in 1900, strictly speaking, the technology of remote sensing evolved gradually into a scientific discipline only after World War II. Like most other mapping technologies, the early developments in remote sensing were mainly driven by military use, with civilian applications emerging much later. Today, the range of remote sensing applications varies from archeology, agriculture, cartography, civil engineering, meteorology and climatology, coastal studies, emergency response, forestry, geology, geographic information

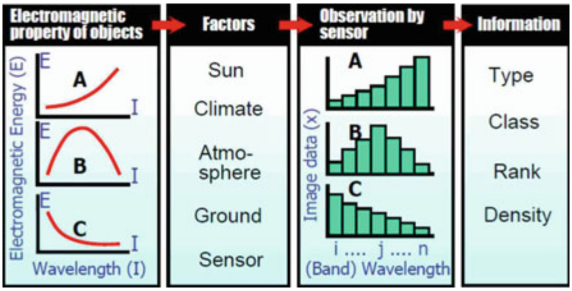

Fig. 11.2 Flow of remote sensing. *Source* Murai (2004)

systems, hazards, land use and land cover, natural disasters, oceanography, water resources, etc. Furthermore, the introduction of high spatial resolution sensors and the development of new image analysis algorithms, has given an impetus to new applications in non-conventional areas like urban mapping, disaster management, location-based services, car and pedestrian navigation, etc.

11.2 Principles of Electromagnetic Radiation

11.2.1 Electromagnetic Spectrum

Electromagnetic radiation, whose major source is the Sun, is fundamentally a carrier of electromagnetic energy. The electromagnetic radiation, which travels in the form of waves at the speed of light (denoted as c and equals to 3×10^8 ms^{-1}) is known as the electromagnetic spectrum. The waves propagate through time and space oscillating in all directions perpendicular to their direction of travel. According to the quantum wave theory, electromagnetic radiation propagates as a traverse wave comprising of both an electric field (E) and a magnetic field (H). These two fields are located at right angles to each other and travel at the speed of light.

Electromagnetic radiation is defined by four basic elements namely; *frequency* or *wavelength*, *transmission direction*, *amplitude*, and *plane of polarization*. It is these four elements, which influence the kind of information that can be extracted from electromagnetic radiation. They also effectively determine the characteristics of remote sensing data or images cues such as colors, tones or geometric shape of objects. The wavelength (λ) is defined as the distance between successive crests of the waves. The frequency (μ) is the number of oscillations completed per second. On the other hand, the amplitude defines the maximum positive displacement from the undisturbed position of the medium to the top of a crest. The plane of polarization represents the plane of the electric field and is important in microwave remote sensing (see, e.g., Awange and Kiema 2013).

By scientific convention, the *electromagnetic spectrum* is divided into different portions. The major divisions of the electromagnetic spectrum ranging from short-wavelength, high-frequency waves to long-wavelength, low-frequency waves, include gamma rays, x-rays, ultraviolet (UV) radiation, visible light, infrared (IR) radiation, microwave radiation, and radio waves. Because of the spectral absorption characteristic of atmospheric molecules in certain regions of the atmosphere, otherwise referred to as the *blocking effect*, only certain parts of the electromagnetic spectrum are useful in remote sensing. These regions represent the *principal atmospheric windows* and define the bands employed in remote sensing as shown in Fig. 11.3.

The *ultraviolet* or UV portion of the spectrum has the shortest wavelengths which are practical for remote sensing. This radiation is just beyond the violet portion of the visible wavelengths, hence its name. Some rocks and minerals fluoresce or emit visible light when illuminated by UV radiation. The visible spectrum is a very narrow band whose wavelength ranges from between 0.3 and 0.7 µm. However, it is a very important part of the electromagnetic spectrum that is particularly critical in photogrammetry and satellite remote sensing. In addition, the light which our eyes—"our remote sensors"—can detect is part of the visible spectrum.

The *infrared* (IR) region can be divided into two categories based on their radiation properties—the *reflected IR* and the *emitted or thermal IR*. Radiation in the reflected IR region is used for remote sensing purposes in ways very similar to radiation in the visible portion as shown in Fig. 11.4a. The reflected IR covers wavelengths from approximately 0.7–3.0 µm. The thermal IR region is quite different than the visible and reflected IR portions, as this energy is essentially the radiation that is emitted from the earth's surface in the form of heat (see Fig. 11.4b).

The thermal IR covers wavelengths from approximately 3.0–100 µm. The principle of black body radiation is relevant in understanding the operation of thermal remote sensing and is articulated in most classical remote sensing literature, see e.g., Lillesand et al. (2010), Richards (1994), etc. While reflected IR images can yield important information on the health status of crops and vegetation, thermal IR sensors have been employed to support rescue operations in disaster events like earthquakes, fires, etc.

The *microwave regions* represent the portion of the electromagnetic spectrum that has raised most interest to remote sensing in recent times. It covers a vast wavelength region that extends in wavelength from about 1 mm to 1 m (see Fig. 11.4c). The microwave region is further subdivided into several other bands like P, L, C, X and K

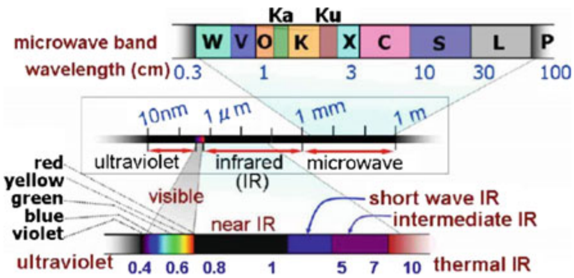

Fig. 11.3 Bands used in remote sensing. *Source* Murai (2004)

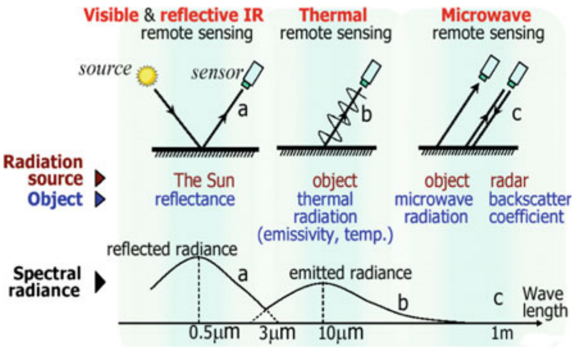

Fig. 11.4 Types of remote sensing. *Source* Murai (2004)

bands. Microwave remote sensing uses microwave in both passive and active modes. Microwaves can be emitted from the earth, from objects such as cars and planes, as well as from the atmosphere.

These microwaves can be detected to provide information, such as the temperature of the target that emitted the microwave. Most passive microwave sensors are characterized by low spatial resolution. Active microwave sensing systems such as Radio Detection And Ranging (RADAR) provide their own source of microwave radiation that is fired in the form of a radar pulse towards the targets. They are then able to detect and record the energy that is backscattered from the targets as shown in Fig. 11.4c. More detailed discussion on microwave remote sensing is presented in Awange and Kiema (2013).

11.2.2 Interaction with the Atmosphere and Targets

As the electromagnetic energy travels through the atmosphere from either the energy source or the target, some *absorption and/or scattering* will inevitably take place. Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents, which absorb electromagnetic radiation. As mentioned above, it is only in those regions of the electromagnetic spectrum where no or slight absorption occurs, otherwise referred to as the *principal atmospheric windows*, where meaningful remote sensing can be practiced.

Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path resulting in attenuation of the electromagnetic radiation. Scattering is mainly caused by nitrogen (N_2) and oxygen (O_2) molecules, aerosols, fog particles, cloud droplets, and raindrops. The type of scattering that results is influenced by the relative size of the atmospheric molecules and particles *vis á vis* the wavelength of the incident energy and will thus vary from one atmospheric region to the other. Three different types of scattering can be distinguished: *Rayleigh scattering*, *Mie scattering* and *Non-selective scattering* in the upper, mid and lower atmospheric regions, respectively.

Whereas Rayleigh scattering is the reason why the sky appears blue, non-selective scattering is the reason for fog and clouds appearing white.

Different types of interactions will occur when the incident electromagnetic radiation finally hits or connects with the targets. The specific type of interaction will depend on the properties of both the target and the wavelength of the incident electromagnetic radiation. *Reflection* occurs when radiation bounces off the target and is then redirected. When the target surface is smooth, *specular reflection* results, where all (or almost all) of the energy is directed away from the surface in a single direction. When the target surface is rough, the energy is reflected almost uniformly in all directions, in which case *diffuse reflection* occurs. Most earth surface features lie somewhere between perfectly specular or perfectly diffuse reflectors.

Absorption occurs when electromagnetic radiation is absorbed by the target. *Transmission* occurs when electromagnetic radiation passes through a target. For any given material, the amount of solar radiation that reflects, absorbs, or transmits varies with wavelength. As discussed in Sect. 11.1, it is this important characteristic of matter that makes it possible to identify different substances or features and distinguish between them on the basis of their *spectral signatures* (spectral curves) in remote sensing.

For demonstration purposes, Fig. 11.5 shows the *spectral reflectance curves* for vegetation, water and dry and wet soils. While vegetation has a unique pattern, the spectral reflectance for soil varies depending on the moisture content with dry soil exhibiting higher reflectance than wet soil. The main part of water, except for shorter wavelength is absorbed with less reflection. Furthermore, Fig. 11.5 also shows that the near infra-red band represents the best region within which to distinguish between vegetation and most other object features like water.

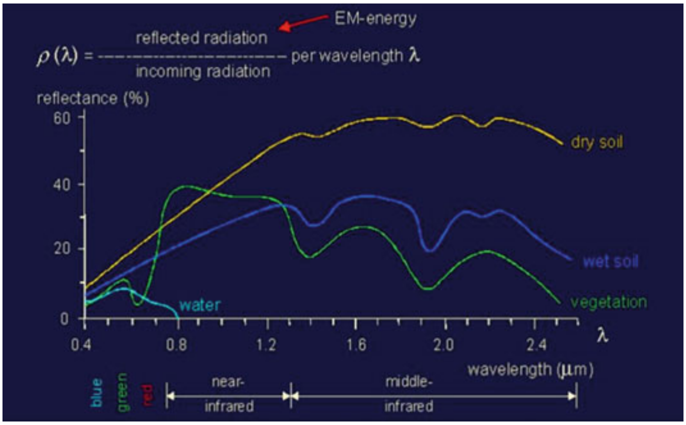

Fig. 11.5 Spectral curves for some features. *Source* CCRS (2012)

11.3 Passive Versus Active Remote Sensing

On the basis of the scope of application and type of electromagnetic radiation employed, remote sensing may be divided into (Weng 2010): (a) *satellite remote sensing* (when satellite platforms are employed), (b) *photogrammetry* (when photographic images are used to record reflected visible energy as discussed in Awange and Kiema (2013), (c) *thermal remote sensing* (when the thermal infrared portion of the electromagnetic spectrum is used), (d) *microwave remote sensing* (when microwave wavelengths are employed as described in Awange and Kiema (2013), and (e) *LiDAR* or *laser scanner remote sensing* (when laser pulses are directed toward the target and the distance between the sensor and the target is estimated premised on either the return time for pulse ranging or the phase difference for side tone (continuous wave) ranging as described in Awange and Kiema (2013).

Based on how energy is used and detected, one can distinguish between two different forms of remote sensing (i) passive- and (ii) active remote sensing. Passive remote sensing systems record the reflected energy of electromagnetic radiation or the emitted energy from the Earth, such as cameras and thermal infrared detectors. On the other hand, active remote sensing systems send out their own energy and record the scattered energy received upon interaction with the Earth's surface, such as radar imaging systems and LiDAR.

One of the advantages of active sensors over their passive counterparts is that they can be used during both day and night or in most weather conditions. In addition, active remote sensors are also able to penetrate through cloud cover. This is unlike passive remote sensors for which sunlight is critical to their successful operation and cloud cover is an impedance and is thus undesirable. It is also possible to generate different imagery with different information content for the active remote sensors like radar imagery by simply altering the wavelength (or frequency) and the polarization of the transmitted and received signals.

11.4 Concluding Remarks

From its humble beginning, remote sensing has grown in stature over the past half century or so to influence virtually all aspects of human endeavor and the environment. Coupled with the availability of historical remote sensing (time-series) data, the reduction in data cost and increased spatial resolution, remote sensing technology appears poised to make an even greater impact on many socio-economic and political endeavors of mankind. Notably, the number of remote sensing applications is very impressive today, with many new applications emerging even in non-traditional areas like urban mapping, disaster management, location-based services, car and pedestrian navigation, etc.

To realize the full potential of this mapping technology, however, it is imperative to integrate remote sensing with other related technologies that provide and deliver geospatial data and information such as *Global Navigation Satellite Systems* (GNSS), *inertial mapping units* (IMU) or other *rotation sensors*, *Geographic Information Systems* (GIS), *wireless sensor networks*, *Global System for Mobile Communication* (GSM), and the *Internet*.

In view of the multi-faceted and increasingly complex nature of most problems confronting humanity today, it is critical that the integration of the above technologies be implemented within the framework of a *decision support system* (DSS) elucidated in Sprague (1980), Bhatt and Zavery (2002), Shim et al. (2002), Power (2004), etc. Using disaster as a typical example, whereas mapping technologies like remote sensing, GNSS and GIS would provide the basic support in pre-event preparedness, response and monitoring, and post-reconstruction in disaster management, communication satellites and the Internet would help in disaster warning, relief mobilization and telemedicinal support (Jayaraman et al. 1997). To leverage from these diverse technologies and to effectively respond to disasters in a coordinated, efficient and timely manner would call for building of the necessary DSS capability within a GIS platform.

References

Awange JL, Kiema JBK (2013) Environmental geoinformatics, monitoring and management. Springer, Berlin

Bhatt GD, Zavery J (2002) The enabling role of decision support systems in organizational learning. Decision Support Syst 32:297–309

CCRS (2012) Canada Centre for Remote Sensing Remote Sensing Tutorial. http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/. Accessed 24 July 2012

Jayaraman V, Chandrasekhar MG, Rao UR (1997) Managing the natural disasters from space technology inputs. Elsevier Science Ltd., Great Britain

Jensen JR (2009) Remote sensing of the environment: an earth resource perspective. Prentice Hall, Upper Saddle River

Kramer HJ (2002) Observation of the earth and its environment: survey of missions and sensors. Springer, Berlin

Lillesand TM, Kiefer RW, Chipman JW (2010) Remote sensing and image interpretation, 7th edn. Wiley, New York

Murai S (1999) GIS work book: fundamental and technical courses, vols 1 and 2. National Space Development Agency

Murai S (2004) Remote sensing and GIS courses - distance education, Japan International Cooperation Agency (JICA)-Net

Power DJ (2004) Specifying an expanded framework for classifying and describing decision support systems. Commun Assoc Inf Syst 13:158–166

Richards JA (1994) Remote sensing digital image analysis: an introduction. Springer, Berlin

Shim JP, Warkentin M, Courtney JF, Power DJ, Sharda R, Carlsson C (2002) Past, present and future of decision support technology. Decision Support Syst 33:111–126

Sprague RH (1980) A framework for the development of decision support systems. MIS Q 4:1–26

Weng Q (2010) Remote sensing and GIS integration: theories, methods, and applications. McGraw-Hill, New York, 416pp

Chapter 12
Geographical Information System (GIS)

Knowing where things are, and why, is essential to rational decision making

—Jack Dangermond, Founder ESRI

12.1 Basic Concept

Geographic Information System (GIS) is defined as a special type of information system that is used to input, store, retrieve, process, analyze and visualize geospatial data and information in order to support decision making, see e.g., Aronoff (1989), Tomlinson (2007), Longley et al. (2005), Konecny (2003), Burrough (1986), Murai (1999), etc. Hence, a GIS is basically a computer-based information system for handling spatially referenced data and information. In the early years after its emergence in the mid 1960s, GIS was viewed essentially as a mere tool—a spatial decision support tool. However, over the years GIS has evolved dramatically from being a simple tool of automated mapping and data management into a sophisticated spatial data-handling and analysis technology and, more recently, into *geographic information science and technology* (GIS&T).

Weng (2010) articulates that GIS today is far broader and harder to define with many people preferring to define its domain as GIS&T. Moreover, it has become embedded in many academic and practical fields with the net result that the GIS&T field today is largely a loose coalescence of groups of users, managers, academics, and professionals all working with geospatial information. Furthermore, each group has a distinct educational and cultural background and identifies itself with particular ways of approaching particular sets of problems (Weng 2010).

In principle, GIS handles geographic data, which include both spatial and attribute data that describe geographic features. Whereas spatial data describe the location and shape of geographic features and their spatial relationships, attribute data describe the characteristics of spatial data. Traditional information systems for decision support, like the classical management information systems, were originally designed

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to handle only non-spatial data such as salary and personnel data, stock inventories, bank account management data, etc. On the other hand, geographic location captured through the use of geospatial data is the cornerstone of GIS. In the past, one could without ambiguity distinguish between the characteristics of spatial and non-spatial information systems. Today, however, it is now widely recognized that even traditional information systems could have better utility if the spatial dimension of the data they handle could be extracted and included in the analysis. This has resulted in a narrowing of the divide between spatial and non-spatial information systems, thereby creating many new applications in GIS.

There are several reasons and situations that would occasion the need for a GIS. According to Konecny (2003), these include among others the fact that;

- geospatial data are poorly maintained (especially in many developing countries),
- maps are out of date,
- data and information are inaccurate,
- geospatial data are inconsistent,
- there is no standard,
- there is no data sharing,
- there is no data retrieval service, and
- there is no scientific decision making etc.

Once a GIS is fully implemented, numerous benefits accrue including Konecny (2003);

- geospatial data are better maintained in a standard format,
- revision and updating are easier,
- geospatial data and information are easier to search, analyze and represent,
- more value added products are output,
- geospatial data can be shared and exchanged,
- overall productivity is improved,
- time and cost are saved, and
- better and informed decisions are made, etc.

Some of the generic questions that any serious GIS is expected to answer include:

(1) Where is it......? (*Location question*; identifies the geographic location(s) that satisfy certain conditions)
(2) What is there.......? (*Basic inventory question*; examines what exists at a particular location)
(3) What spatial patterns exist.....? (*Relation question*; analyzes the spatial relationship between objects of geographic features)
(4) Why there.......? (*Cause and effect question*; explores various driving factors and consequence(s) thereof)
(5) What has changed since.......? (*Trend question*; identifies geographic occurrence or trends that have changed or are in the process of changing)

(6) What if.......? (*Modeling question*; analyzes various scenarios based on model and given conditions, e.g., optimum path, a suitable land, risky area against disasters, etc.).

12.2 Key Components

The key components of GIS are a computer system, geospatial data, and users as shown in Fig. 12.1. A computer system for GIS consists of hardware, software, network, and procedures designed to support the data capture, processing, analysis, modeling and visualization of geospatial data. The basic hardware items for GIS includes the host computer, a digitizer, printer, plotter, monitor, keyboard, mouse, plus the associated cabling and external storage media usually in a networked environment.

Besides standard software for mundane tasks like operating system, programming, graphics, networking, etc., GIS software will also be required. This falls in the category of application software. There are various types of GIS software available in the market and by extension different GIS systems e.g., Desktop GIS (normal software), Server GIS (expensive software allowing sharing with many users), Web GIS (soft-

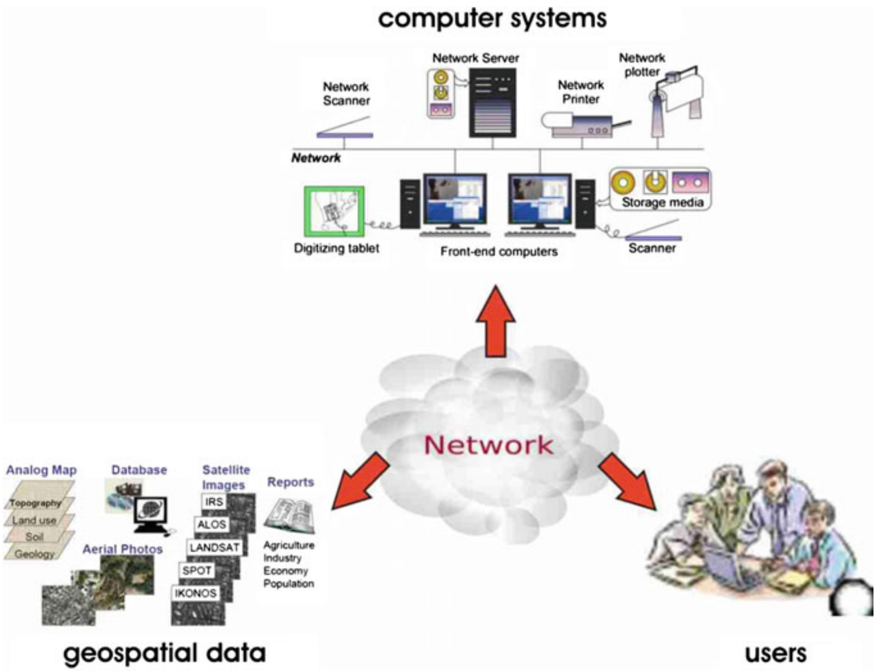

Fig. 12.1 Key components of a GIS

ware using web browser described in Chap. 13), Mobile GIS (working with Personal Digital Assistant (PDA)), etc. It is important to understand the required computer systems in GIS and identify the required GIS hardware and software characteristics.

A GIS with the best hardware and software combination will still fail if there is inadequate or inappropriate input data. This is true since data is the raw material from which information is processed. Data in a GIS consists of both spatial and attribute data. The data is kept in a database and is managed by a database management system (DBMS). In addition, an appropriate organizational environment is essential for proper functioning of GIS hardware and software. Specifically, organizational procedures must be put in place in order to create awareness about the GIS and fit it appropriately in the overall operations of the concerned organization. Some important issues involved in setting up GIS include the development of standards, access protocols, database administration, quality assurance and system security.

Within the knowledge economy and in many businesses, staff are usually seen as the prime business asset and the factor that differentiates one organization from another. Longley et al. (2005) reiterates that the supply of GIS experts and GIS-literate people is a critical factor in determining the rapidity of up-take of the existing facilities and their successful use. People in GIS consist of staff that operate the system, the users of the system and external consultants that may be called from time to time to advise on different strategic, technical and project issues. For a medium to large GIS establishment, the core GIS team will usually comprise of the following personnel: GIS manager, database administrator, system manager, GIS analyst, GIS programmers, data entry clerks, etc. In a fairly small GIS set up, only the GIS analyst, programmer and data entry clerk may be necessary with the GIS analyst doubling as the GIS manager.

At a practical level and in order to function properly, the various GIS components need to be synchronized to match the system requirements and desired applications. For instance, the purchase of hardware must be matched with that of software. Similarly, the right human resources must be put in place to transform the geospatial data into information and knowledge for decision support. Resources must also be availed to capture the required geospatial data, which incidentally constitutes the most expensive GIS component as shown in Fig. 12.2a. Installing a GIS can be a fairly expensive

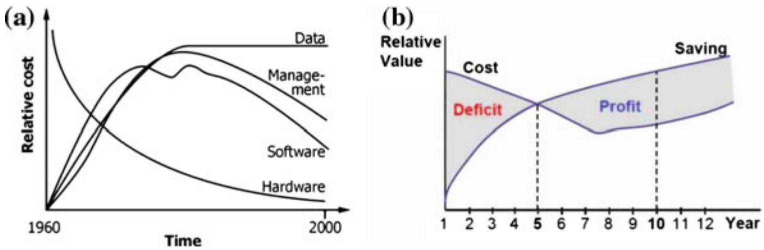

Fig. 12.2 GIS cost aspects. *Sources* **a** Konecny (2003) and **b** Murai (2004)

Table 12.1 Basic GIS functions

Basic function	Description
Data input and preprocessing	Map digitizing, map/photo scanning, editing, topology building, format conversion etc.
Database management	Data archiving, data retrieval, data updating etc.
Spatial analysis	Query, measurements, reclassification, coverage rebuilding, overlay operations, connectivity analysis etc.
Graphic output and visualization	Map projection, graphic representation, map production, DEM generation, bird's eye views etc.

exercise requiring significant capital investment for a minimum period of between 5–6 years before any profits can be realized as shown in Fig. 12.2b.

12.3 Basic Functions and Applications

There are many software available in the GIS market today. Although the most reknown of these are proprietary in nature, increasingly many open source GIS software are being produced. As a matter of fact, open source GIS is a rich and rapidly expanding field of endeavor as confirmed by Sherman (2008), who carried out a comprehensive survey of open source resources for GIS users, and the impressive list of 356 software and 25 geodatasets available at the freeGIS project website.[1] Despite the fact that different GIS software have different design and architecture, there are certain basic functions that will be characteristic of any serious GIS software as presented in Table 12.1.

Examples of major GIS software with their respective costs are outlined in Table 12.2. One can easily distinguish between open source and freeware GIS software and commercial and proprietary GIS software. For commercial and proprietary GIS software it is important to note that on average an upgrade costs anything between 1/3 and 1/2 of the basic software price. Moreover, each extension module is an added cost and for some GIS software houses it may cost several times more than the basic software. In practice, academic and multiple-user licenses are also available for commercial and proprietary GIS software. As mentioned in Sect. 12.2, to achieve optimal usage, GIS software needs to be matched against the appropriate hardware following an assessment of the user requirements. Ultimately, however, in selecting an appropriate GIS software the total cost of ownership, including the acquisition, maintenance, and manpower costs needs to be evaluated.

GIS has evolved today into an integrated multidisciplinary science with many disciplines having contributed to its development in different ways and to varying degrees. Disciplines that traditionally have researched geographic information

[1] http://www.freegis.org.

Table 12.2 Examples of major GIS software in the market (2012)

GIS software	Software house	Single desktop user license cost (US$)
ArcGIS	ESRI	1,500
Geomedia	Intergraph	1,500
MapInfo	Mapinfo	1,295
ILWIS	ITC (Faculty of Geo-Information Science and Earth Observation, University of Twente)	Free
IDRISI	Clark University	1,250
GRASS	GRASS Information Center	Free
SIS	Cadcorp	–
ER Mapper	ER Mapper	–

technologies include cartography, remote sensing, geodesy, surveying, photogrammetry, etc. Additionally, disciplines that traditionally have researched digital technology and information include computer science in general and databases, computational geometry, image processing, pattern recognition, and information science in particular (Weng 2010). Disciplines that traditionally have studied the nature of human understanding and its interactions with machines include particularly cognitive psychology, environmental psychology, cognitive science, and artificial intelligence (Weng 2010).

The incredible potential of GIS is perhaps best exemplified by the fact that at least 80 % of public and private decision-making is based on some spatial or geographic aspect Fédération Internationale des Géométres (2001). As an *enabling technology*, GIS has diverse and almost unlimited potential for applications, ranging from simple to complex, local to global, rural to urban, etc. Coupled with a digital map, GIS allows a user to see locations, events, features, and environmental changes with unprecedented clarity, showing layer upon layer of information such as environmental trends, soil stability, pesticide use, migration corridors, hazardous waste generators, dust source points, and at-risk water wells. For example, GIS mapping/cartography was used extensively in the Ogoniland hydrocarbon pollution assessment with more than 200 maps generated at a scale of 1:5,000 (see Sect. 19.1.3.1, p. 390).

Although GIS was first applied to environmental and natural resource management, it has found application in many classical fields that study physical or human aspects of the Earth including geography, global science, sociology, political science, epidemiology, anthropology, demography, etc. GIS has also found numerous applications in the area of management and decision making, such as in resource inventory and management, urban planning, land information systems, facilities management, marketing and retail planning, vehicle routing and scheduling, etc.

In line with the basic objective of this book, GIS can be used to support environmental monitoring and management in a number of ways, namely;

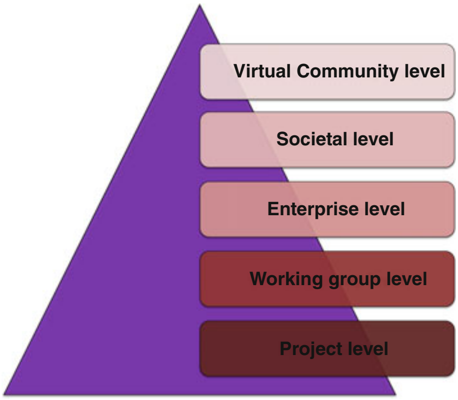

Fig. 12.3 GIS implementation levels

(a) Collecting and managing baseline data. Most environmental monitoring activities require that baseline data be collected a priori to serve as reference in subsequent monitoring activities (see e.g., Awange and Kiema (2013) for REDD[2] project baseline mapping).
(b) Tool for designing and managing monitoring programs. Given the diverse data sets employed in environmental monitoring from different sources e.g., remote sensing, GNSS, desk reports, etc., GIS provides a framework for integrating and managing all these different data. Monitoring programs can then be designed and managed using the developed GIS database.
(c) Managing data requests for multiple users. Environmental monitoring is a multidisciplinary activity with inputs and requests from different players including the local community. GIS provides a suitable platform for sharing data both horizontally and vertically, especially when integrated within a *spatial data infrastructure* (SDI) framework.
(d) Analysis and modeling of management and development scenarios. As discussed in Awange and Kiema (2013), the main strength of GIS lies in spatial analysis. Among other spatial analyses possible, GIS allows the modeling of various "what if" scenarios that enables appreciation of the likely consequences of different developments, without necessarily having to experience them in practice. For example, it is possible to get a graphic visualization of the possible effects of unmitigated forest destruction.

Finally, each application area of GIS requires a special treatment and must examine data sources, data models, analytical methods, problem-solving approaches, and planning and management issues (Weng 2010). Furthermore, depending on the scope of application, GIS can be implemented at different levels ranging from a single project to virtual community level, where for instance cloud GIS solutions are employed, through working group-, enterprise- and societal levels as highlighted in Fig. 12.3.

[2]Reductions in Emissions from Deforestation in Developing countries.

12.4 Reasons for Success or Failure

The implementation of GIS will either be a success or failure depending on several factors. Tomlinson (2007) summarizes the following six elements as representing the most important factors for implementing a successful GIS:

(1) *Data input* comprises anything between 70–80 % of the total cost in GIS. This explains why serious attention should be accorded to the selection and classification of required geospatial data for GIS projects, while taking into consideration the digitizing method to be employed.
(2) *Maintenance of database* is critical since the quality of decisions made from a GIS depends largely on the quality of the GIS database. It is evident that the maintenance of database is a key issue upon which the success of GIS is centered. In particular, maintaining data quality and routinely updating the system is imperative.
(3) *Consensus of supporters* is important to the success of GIS projects. Indeed, the supply of GIS experts and GIS-literate people is a critical factor in determining the rapidity of up-take of the existing GIS facilities and their successful use. To achieve success, not only top managers but also other administrative staffs and engineers should support the GIS project. Ideally, GIS should be mainstreamed into the various activities within the organization itself.
(4) *Customizing software* transforms generic software to customer/application-friendly software. There are various reasons for customizing GIS software including to: add new functionality to applications; embed GIS functions in applications and create specific purpose applications. The tools required for customization of GIS software include availability of an appropriate programming language such as *Visual Basic* or *Java* and an *Integrated development environment* (IDE).
(5) *Data sharing* is increasingly being appreciated worldwide as an important factor in the economical and effective use of geospatial data in general. This represents one of the important factors that can be relied upon to minimize the total cost of data input and also to maximize the use of the database. Political and administrative problems should be solved to promote the data sharing for a successful GIS. The optimal sharing and standardization of GIS data is best realized once a *spatial data infrastructure* (SDI) has been put in place.
(6) *Education and training* is very important to understand GIS concept, goals and techniques. They should be organized into three levels for makers, professionals and technologists. However, there is need to modify GIS education and learning to take cognizant of the fact that GIS is now a much broader discipline than simply a collection of tools and techniques. Hence, drawing from the paradigm of geographic information science and technology (GIS&T), more emphasis should be placed upon concepts and methods for geographic problem solving in a computational environment (UCGIS 2003).

Conversely, several reasons have been identified as being responsible for the failure of many GIS projects including Tomlinson (2007):

(1) *Lack of vision* and more specifically, the absence of *specific*, *measurable*, *achievable*, *realistic* and *timely* (SMART) objectives will in the long run lead to failure in the implementation of GIS. Precise and specific targets and goals need to be drawn to mitigate against failure.
(2) *Lack of long term plan* may also contribute towards failure in GIS. Cost-benefit analyses have demonstrated that the full benefits of GIS are only realized after about 5–6 years (see Fig. 12.2b). This means that the initial phase of implementing GIS is essentially one of capital investment, with the costs incurred far outweighing any possible benefits. However, inability to demonstrate benefits in the interim period may actually lead to unsuccessful GIS. Similarly, poor planning or lack of a long term plan will result in unsuccessful GIS. There is also need to periodically update GIS data and upgrade GIS hardware and software accordingly to match user and system requirements.
(3) *Lack of system analysis* is likely to precipitate failure in GIS. There is need to adopt a system approach and integrate appropriate restructuring to avoid failure in the implementation of GIS projects. Similarly, un-supportive organizational structure will lead to unsuccessful GIS.
(4) *Lack of user's access* will in the long run lead to failure. Besides data, users constitute an integral component in GIS (see Sect. 12.2). There is need to equip the different cadres of GIS users will appropriate knowledge, skills and experience through customized training and full user participation. To avoid failure it is also important to provide documentation for all requisite procedures.
(5) *Lack of support by decision makers* and particularly, lack of executive-level commitment and support, due to one reason or the other, will lead to failure in GIS. Similarly, lack of core funding, or undesirable political pressure, especially where these change rapidly will only lead to unsuccessful GIS.
(6) *Lack of expertise* is a sure way to failure as GIS is a fairly technical discipline. Inadequate oversight of key participants, inexperienced managers or absence of consultation will no doubt lead to failure in GIS.

12.5 Concluding Remarks

As a special type of information system, which basically deals with geospatial data, GIS has proved to be quite a versatile *science and technology* that offers remarkable spatial decision support capability. It is particularly well suited for use in fairly complex practical applications, like those prevalent in environmental monitoring and management, in which several different and sometimes competing factors often characterized by complex relationships, need to be considered in decision making. GIS allows the stochasticity of the different pertinent variables to be brought together within a common framework to make better and informed decisions. Moreover, appropriate models can be integrated to customize and tailor GIS software in order to address and suit specific applications.

Perhaps, one of the foremost advantages of GIS is the ability to investigate worst case scenarios and appreciate the underlying factors in a better and more meaningful way, without having to wait to experience these first in practice. For example, using GIS it is possible to model and examine the possible impact of an oil spill to an ecosystem a priori. This would allow for appropriate mitigation measures to be put in place well in advance to prevent the occurrence of such an environmental disaster, or to deal with the possible consequences by fine-tuning response and recovery strategies, if such a disaster was to occur in future.

By and large, the quality of the decisions made from a GIS is influenced largely by the quality of the geospatial data in the GIS database. This data needs to be accurate, complete, consistent and up-to-date. As articulated in this chapter, alongside this basic and critical requirement, various other factors also need to be in place to ensure that GIS succeeds in contributing positively to influencing the way that better, timely and informed decisions are made.

References

Aronoff S (1989) Geographic information systems: a management perspective. WDL Publications, Ottawa

Awange JL, Kiema JBK (2013) Environmental geoinformatics, monitoring and management. Springer, Berlin

Burrough PA (1986) Principles of Geographical Information Systems for Land Resources Assessment. Oxford University Press, New York, 50p

Fédération Internationale des Géométres (2001). http://www.fig.net. Accessed 11 June 2010

Konecny G (2003) Geoinformation: remote sensing, photogrammetry, geographic information systems. Taylor and Francis, London

Longley PA, Goodchild MF, Maguire DJ, Rhind DW (2005) Geographic information systems and science. Wiley, West Sussex

Murai S (1999) GIS work book: fundamental and technical courses, vols 1–2. National Space Development Agency

Murai S (2004) Remote sensing and GIS courses - distance education. Japan International Cooperation Agency (JICA)-Net

Sherman GE (2008) Desktop GIS: mapping the planet with open source tools. The Pragmatic Bookshelf, Raleigh

Tomlinson RF (2007) Thinking about GIS: geographic information system planning for managers. ESRI Press, New York

UCGIS (University Consortium for Geographic Information Science) (2003) The Strawman report: development of model undergraduate curricula for geographic information science and technology. Task Force on the development of model undergraduate curricula. University Consortium for Geographic Information Science

Weng Q (2010) Remote sensing and GIS integration: theories, methods, and applications. McGraw-Hill, New York, 416p

Chapter 13
Web GIS and Mapping

Thanks to … a range of Web-based services, the average citizen is able to be a consumer and a producer (aprosumer) of geographic information.

—Michael Goodchild et al. (2012)

13.1 The Web and Its Influence

The Internet and web-based technology has dramatically influenced the access to and dissemination of information among communities, locally, and globally. This is no less true in the domain of geographic information systems (GIS), which have traditionally been constrained in terms of information access and the communities that use them. Geospatial data has traditionally been captured and managed within individual and separate organizational databases with access by a limited number of expert users. Now, with the integrated use of the web, not just geospatial data, but also the functionality of GIS can be accessed globally by citizens and non-experts.

The web brings together different users together with the ability for geospatial data to be retrieved from separate databases, accessed by multiple applications such as GIS, digital earth viewers and map servers, and integrated with the location of mobile devices that also can directly access the web (see Fig. 13.1). This combination is very rich and powerful in that users all over the world, connected to any fixed or mobile device on the web, can access multiple applications and associated data from anywhere and anytime.

The advent of digital earth technologies, such as Google Earth, Microsoft Virtual Earth, ESRI ArcGIS Explorer and NASA World Wind, have opened up geospatial imagery and other data to the average citizen who can, not only access this information via the web, but also be able to contribute and add information of their own. The range of information being integrated in such an environment, as well as the functionality

Invited Chapter in Awange and Kiema (2013) by Prof. Bert Veenendaal of the Department of Spatial Sciences, Curtin University (Australia).

E.A. Sholarin and J.L. Awange, *Environmental Project Management*,
Environmental Science and Engineering, DOI 10.1007/978-3-319-27651-9_13

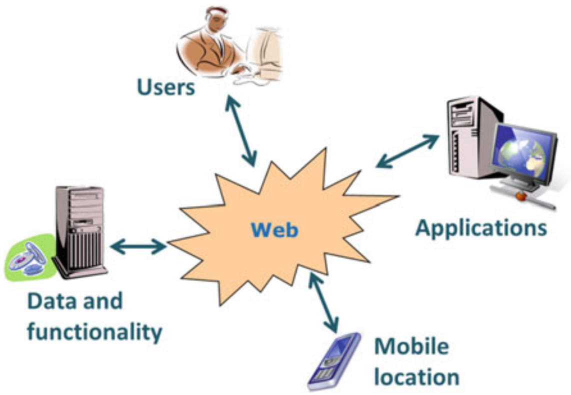

Fig. 13.1 Use of the web for convergence of users, applications, data, functionality and location

permitted on this information continues to expand so that much of what an expert user can access in a GIS is now able to be interacted with by non-expert users using a virtual globe browser online (Craglia et al. 2012; Goodchild et al. 2012; Li et al. 2011).

13.2 Concept and Applications of Web GIS

Web GIS can be defined simply as a GIS that uses web technologies (Fu and Sun 2011). This can practically be realized in a number of ways. Firstly, GIS software systems are increasingly being extended to incorporate access to the web including the ability to retrieve geospatial data in real-time from other web-based databases and services, and provide web-based interfaces from which the GIS can be driven. Secondly, web GIS applications are being established apart from desktop proprietary systems and incorporate much of the functionality and data that would normally be expected in a GIS. These online GISs range from interactive maps with some limited interaction for manipulating the view, to more sophisticated systems that provide a greater range of GIS functionality.

As an example, Fig. 13.2 illustrates an interactive web mapping interface showing imagery of a region near Brisbane in Queensland, Australia, before and after the January 2011 flood disaster. The user can manipulate the vertical black slider bar to reveal and compare the two images. Although simple in concept, the interface is very effective in showing the extent of inundation and of the damage that occurred through the disaster event. Interestingly, this interactive map was used by ABC News in Australia on their web site (ABC 2011).

In the more recent January 2013 flood in Queensland, Australia, ABC News again used an interactive map (ABC 2013). However, this time it had the look and feel of the digital earth interfaces with the map view being driven through mouse controls and having some map control buttons superimposed on the image map (see Fig. 13.3).

Fig. 13.2 Example of an interactive web map showing before/after imagery in the flood disaster for an area near Brisbane, Australia in January 2011. *Source* ABC (2011)

Fig. 13.3 Example of an interactive web map for the January 2013 floods in the region of Brisbane, Australia. *Source* ABC (2013)

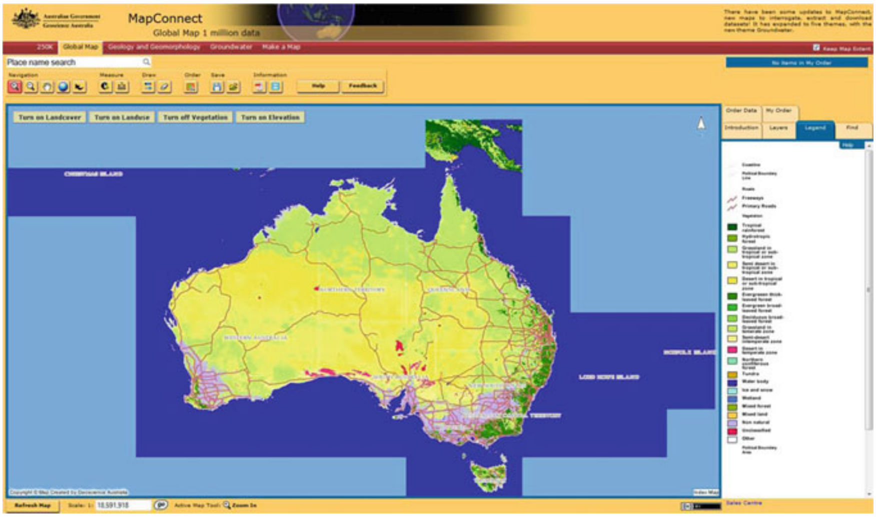

Fig. 13.4 Example of the interactive online map interface of MapConnect. *Source* Geoscience Australia (2012)

Web mapping and web GIS are being used for an increasingly diverse range of purposes and applications. The purposes range from access to data, dissemination of data, browsing of geographic regions and datasets, access to information in proximity to a user, comparing change at a geographic location over time, to even accessing real-time information such as live traffic feeds, real-time temperature and rainfall, and current petrol or gas prices. Applications of web GIS and mapping include disaster recovery and management, travel planning and navigation, regional and national interactive atlases, resource information repository, community health information and customized mapping interfaces catering for selected interest groups or projects.

For example, Geoscience Australia's MapConnect online provides users with access to Australian topographic and resources data (Geoscience Australia 2012). Users can utilize the online mapping interface to browse the data, view it online and download it using the interactive map selection process (see Fig. 13.4). Users can manipulate the map view by panning, zooming, selecting themes such as 250 K topographic maps, global map, geology and geomorphology, and groundwater, as well as selecting geospatial layers such as land cover, land use, vegetation and elevation. They can perform some basic functions such as measuring and drawing, searching and also download or order digital data and maps.

13.3 The Development of Web Mapping

The provision of maps on the web has undergone a number of developments over the past several decades. What started as the provision of images of maps embedded in HTML web pages accessed via an Internet browser are now highly interactive web maps that have the look and feel of a GIS map window and retrieve imagery and GIS data automatically in the background or on an as needed basis (Fu and Sun 2011).

A very early web map, called Map Viewer and built by Xerox Parc, used hyperlinks to provide the user with options of predefined viewing scales, layers, zoom levels and coordinate systems in a series of static hyperlinked HTML pages (Putz 1994). In essence, each combination of user option was embedded as an image in a different HTML page. When accessed, it gave the impression of some dynamic response to a user chosen option for map viewing.

With the development of dynamic HTML with client and server side scripting, it became possible to change information within a specific HTML web page dynamically by generating new HTML or images within the same document. The advent of AJAX technology allowed the content of a web page to be loaded dynamically and in the background while the user is able to simultaneously interact with the page. For web mapping, this meant that appropriate image data could be loaded in the background while the user was simultaneously engaging with the interface to toggle on/off map layers, zoom in or out the current geographic view and pan around the map.

Fig. 13.5 Example of a modern web map interface—The Atlas of Canada. *Source* Government of Canada (2013)

A major development in web mapping was realized with the release of Google Earth in 2006.[1] Users could access, not just 2D, but 3D data over the surface of the earth using an interface that was very intuitive and easy to use for the average non-technical user. This development in essence marked the start of an era of access to geospatial data by the global community (Goodchild et al. 2012).

An example of a modern online and interactive web map is The Atlas of Canada (see Fig. 13.5). This web map, considered to be the first online atlas, comprises a legend from which layers can be selected, and provides basic map manipulation tools for panning and zooming, similar to the functionality found within a desktop GIS. Some of the earliest online maps had buttons or sliding bars to facilitate user interaction. However, the user interface has changed to resemble more closely that of a typical desktop GIS with a legend down the side and icons above to manipulate the map view. More recently, the user interface has taken on the look and feel of the digital earth interfaces such as is used in Google Maps and Google Earth, with which many users globally are now familiar. Note that, as shown in Fig. 13.5, the current version of The Atlas of Canada uses the slider bar for zooming and the directional arrows for panning, in addition to the usual functions of the mouse buttons and scroll wheel that enable the same functionality.

13.4 Web Services

Often we think of the web as a set of pages that can be opened up in a browser and provide text and multimedia to read, watch or listen to. However, when presenting maps on the web, there are potentially many diverse sources of data, which can be combined in some way to produce the resulting map which can be interacted with and manipulated. In fact, access to both data and functionality can be established through the creation and provision of a web service.

A web service is an interoperable component that provides a defined interface and protocol to deliver a service across the web (Booth et al. 2004). The service is implemented using a client–server model. As illustrated in Fig. 13.6, the server provides a service, which is performed by the application logic, and defines an application programming interface (API) that describes the requests, parameters, and responses that make up the interface (Jones and Purves 2008). The client interacts directly with the user and generates the view that the user sees. Depending on the action that the user initiates, the client puts forward a request to the server, receives the response from the server and then displays it in the browser view back to the user. For example, if the user requests a map displaying land cover imagery over the central African continent, then the client Internet browser will request that map from a map server. The map server will assemble the map or associated data and return that to the client where it will then be displayed in the map view window within a browser page for the user to visualize.

[1] www.earth.google.com.

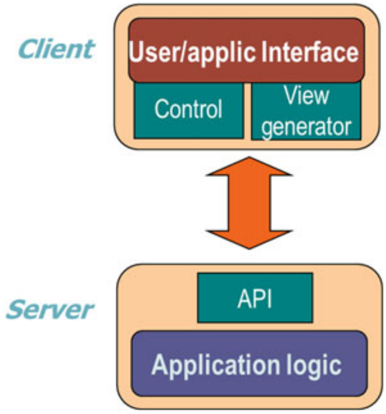

Fig. 13.6 Web services client–server model

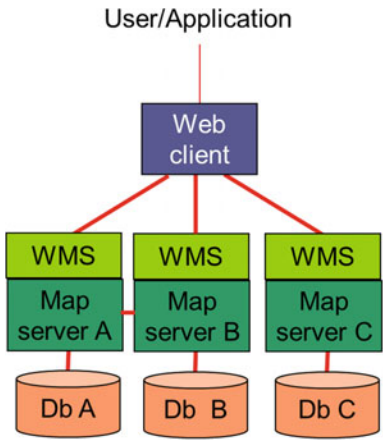

Fig. 13.7 Utilizing the common WMS standard interface to access multiple web mapping services

To facilitate interoperability for geospatial data and functions, the Open Geospatial Consortium (OGC) has developed a number of standard specifications for geospatial web services (OGC 2013). These OGC standards include the Web Map Service (WMS) that provides an assembled map as an image document, Web Feature Service (WFS) that provides geospatial vector-based data using an XML format, Web Coverage Service (WCS) that provides raster-based data, Web Processing Service (WPS) that performs a specified geoprocessing function and responds with the results, and Catalogue Services for the Web (CSW), which provides catalog services for geospatial data on the web. These standards enable users or applications on the client side to utilize a common interface when retrieving information from one or multiple servers. Figure 13.7 illustrates how the WMS standard can be utilized by a client, such as an Internet browser, to retrieve map data from multiple map servers using precisely the same protocol for access.

Geospatial web services can be accessed from within a web page via an Internet browser or from an application program such as a GIS software package, or even from

Fig. 13.8 Accessing a WMS geospatial web service from the WA Atlas web map

another web service via a web services chain. For example, the WA Atlas (Western Australia) provides an online web map interface with a range of data layers available by default (WA Atlas 2013). However, the user can specify further datasets by linking via a WMS interface; this dynamically accesses data layers from other WMS map servers and presents them within the WA Atlas map window. Figure 13.8 illustrates how Public Drinking Water Source areas data is dynamically retrieved from a WMS map server and overlaid with other layers (e.g. roads, towns, rivers, etc.) in the map view.

Many web services have APIs that are customized to the types of services provided and go beyond and outside of the existing standards. For instance, most of the virtual globe providers define their own API, which provides a means for browsers and applications to directly access these services from within a web page. For example, the Geoscience Australia Earthquake Hazards 2012 online map displays earthquake hazard risk on top of additional geospatial layers such as topography, geology, land cover, gravity image or magnetic image (see Fig. 13.9). The background to the map view is imagery from Google using the Google Maps API (developers.google.com). So by linking in to the Google Maps data and functionality (e.g. basic map manipulation tools) using a web service API, a developer is able to extend this with more information, providing the user with options for layer selection, layer viewing opacity, legends, etc.

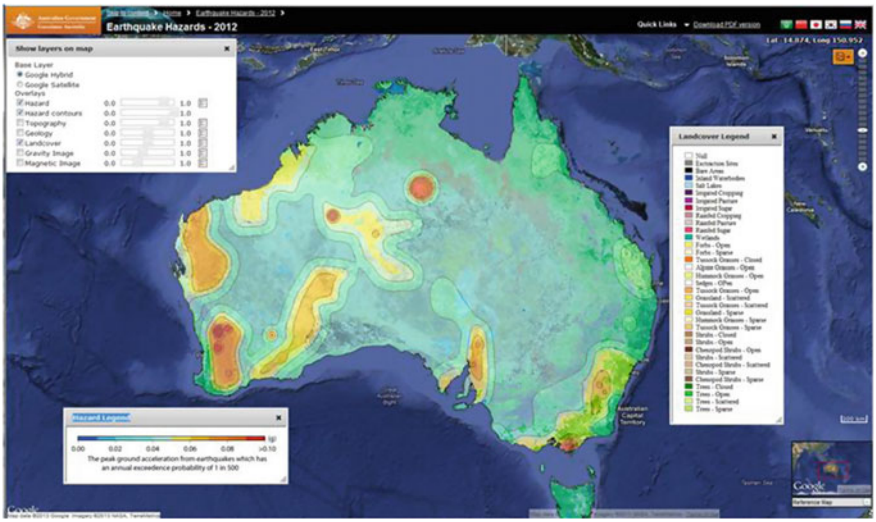

Fig. 13.9 Earthquake hazards 2012 web map utilizing Google Earth imagery in the background. *Source* Geoscience Australia (2012)

13.5 Mobile and Cloud-Based GIS

A fascinating development alongside the web is mobile technology and their use of location. Not only do cell phones and other mobile devices such as laptops, tablet computers, and car navigation systems have access to the cellular network and web, but they are also able to access geographic location via a global navigation satellite system (GNSS) such as the United States' GPS system (see, e.g., Awange 2012). This allows the current mobile location to be integrated into any web-based or mobile application.

The number and range of applications, particularly on mobile devices, that access the location of the mobile device (user) are increasing rapidly. For example, there are mobile applications that use the current location (and movement in location) to determine current speed and direction,[2] popular nearby restaurants,[3] position and path of the sun,[4] mapping tracker and manager of fitness activities (runkeeper.com), plane finder using augmented reality to point the mobile phone camera in the direction of an airplane in flight,[5] tracking the location of mobile devices,[6] etc. This small sample of mobile applications reflects the diversity of applications and means in

[2]https://itunes.apple.com/au/app/speedometer-free-speed-limit/id557871911?mt=8.

[3]http://www.urbanspoon.com/mobile-downloads.

[4]http://www.sunseeker.com/iappint.php.

[5]http://my.pinkfroot.com/page/plane-finder-ar-track-live.

[6]https://itunes.apple.com/au/app/find-my-iphone/id376101648?mt=8.

which the in-built GPS position is being used in interesting and indeed astounding ways that were not previously imagined.

The location used by an application on a mobile device can be the location of the mobile device, or the location of objects and events. Often, non-geographic information about desired objects or events need to be utilized in order to obtain their location. In the case of a home, the street address can be used to derive a location using a process referred to as *geocoding*. More generally, location can be derived from feature names, GPS positioning (e.g., Awange 2012), IP addresses of devices on the Internet, triangulation of WiFi or cell phone devices based on multiple receiving stations and signal strengths, in a process referred to as *geolocating* (Veenendaal et al. 2011). Once the location of objects or events is known, it can be linked or viewed in relation to other objects or events in proximity. When these features and/or event locations are used in conjunction with the current location of a user (mobile device) that is making a request on their mobile device, the information provided can be very rich in content, instant in real-time, and relatively simple to obtain.

Figure 13.10 illustrates how the process works. Users may put forward a request or run an application via their mobile device or some other device on the Internet. The request may be relative to the current location of the mobile device (either their own or of that elsewhere geographically located), for example, querying a nearby restaurant or tracking the movement of a vehicle. The mobile device, such as a mobile phone or car navigation system, obtains its current location using GPS and sends this to the application. The application may request the location of other features by geolocating or by retrieval from a database on the web, possibly through another online application used to perform the appropriate geolocating or query function. This information is then analyzed by the application and the result is returned to the user or mapped via the application on the device they are using.

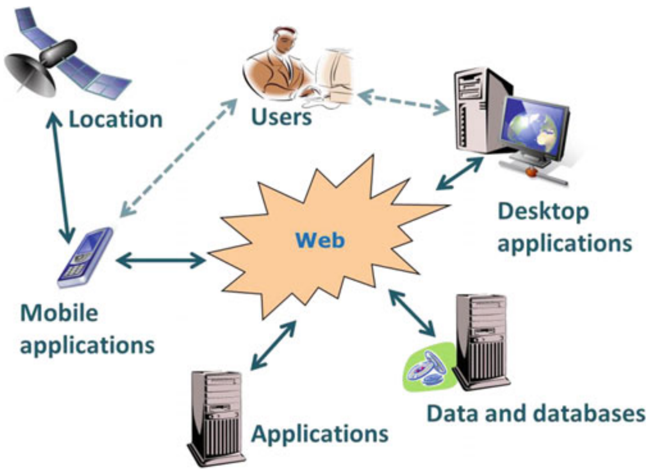

Fig. 13.10 Integrating mobile location into applications in a web environment

Mobile geospatial applications are also very useful as a platform for crowd-sourcing from mobile users and bringing together information at geographic locations or regions. In such situations as natural disaster events, it is crucial to obtain and map information to assist in disaster response and recovery in a timely and coordinated manner.

The Australia Broadcasting Company experimented with crowd sourcing using the Ushahidi open source platform[7] for the floods crisis events in Queensland, Australia (ABC 2013). Information such as messages and photos are sourced from people on the ground using Twitter, SMS, email and the web, and are mapped and viewed via an online interactive map. Figure 13.11 illustrates a crowd sourced map of a region near Brisbane showing messages plotted as points in a region near Brisbane, Queensland. The message selected is a call by the Brisbane City Council for volunteers to assist in the response effort during the December 2010–January 2011 flood disaster. This same platform integrating social networking data, location and online mapping, has been used in numerous disaster situations including the Christchurch, New Zealand earthquake and Japan tsunami and earthquake events of 2011.[8]

As the amount and demand for geospatial information and functionality continues to rise by an increasingly more diverse and geographically dispersed audience, it is not difficult to understand that an increasing amount of data storage and processing infrastructure is required to facilitate this. A solution that is becoming more utilized is a cloud server that maintains and manages the data and functionality services somewhere out there on the Internet, in the cloud (Li et al. 2011). This is an attractive solution in that the hardware infrastructure is outsourced and the software and data infrastructure can be accessed from anywhere on the web.

As an example, the City of Banff in Canada launched an online web mapping site[9] that is hosted on ESRIs ArcGIS Online[10] cloud-based GIS. Although it is not directly visible to the user, the map resides on a cloud server using a web GIS platform that makes it easy to implement and able to be accessed from a range of fixed and mobile devices on the web. The map can be shared with only specified users or groups, or more broadly with the general public. All the basic map manipulation and data layer tools are available together with a choice of base maps delivered from another server in the cloud. Cloud-based infrastructures, services and solutions will continue to develop to meet the ever-increasing demands on access to web-based geospatial and GIS information and services (Craglia et al. 2012).

[7] www.ushahidi.com.

[8] http://blog.ushahidi.com/2011/03/16/crisis-mapping-japans-earthquake-and-how-you-can-help.

[9] http://www.banffmaps.ca.

[10] http://www.arcgis.com/home.

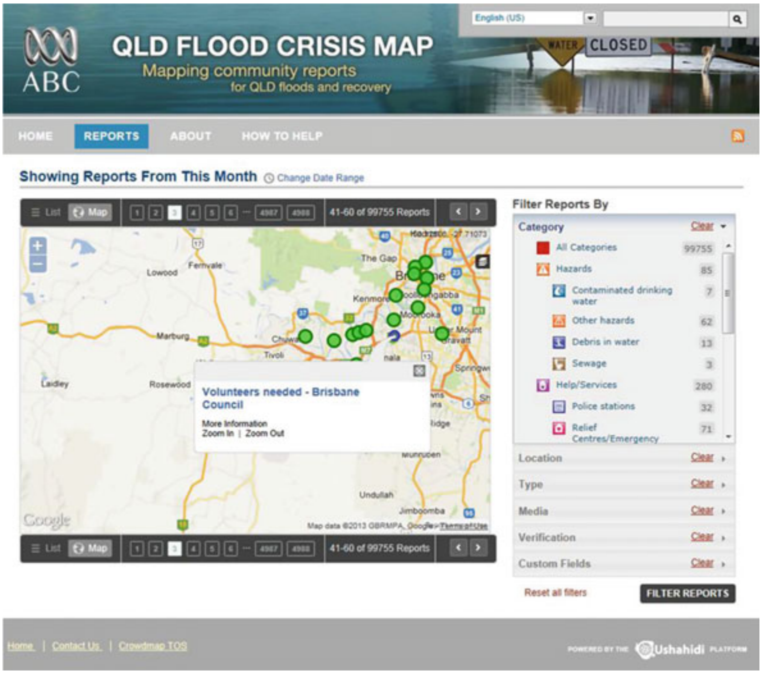

Fig. 13.11 Using crowd-sourced data to compile an online web map as the Queensland flood disaster of 2010/11 unfolded. *Source* ABC (2013)

13.6 Concluding Remarks

Web based GIS and mapping technologies are rapidly developing to meet the increasing demands of users and the global community linked via the web. This is an exciting development that is facilitating the use of geospatial information into many and diverse applications. Whereas GIS has traditionally been confined to specialist systems manipulated by specialist professionals, the web has projected GIS into a global environment and transforming it to meet the needs of the global community and public.

Through the social networked and instant access to information age in which we live, geospatial applications will continue to evolve and be integrated into many applications and work flows across existing and new communities and disciplines. Whether users realize it or not, whether it is explicit or not, web and cloud-based geospatial information and GIS will remain a fundamental and integral part of what we do, when and, importantly, where.

References

ABC News (2011) Brisbane floods: before and after. Australian Broadcasting Corporation. http://www.abc.net.au/news/specials/qld-floods. Accessed 31 Jan 13

ABC News (2013) Interactive: Brisbane flood maps. Australian Broadcasting Corporation. http://www.abc.net.au/news/2013-01-28/interactive-brisbane-flood-maps-released-2013/4487438=overview. Accessed 31 Jan 2013

ABC (Australian Broadcasting Corporation) (2013) Qld Flood Crisis Map: Mapping community reports for QLD floods and recovery. Australia Broadcasting Corporation. https://queenslandfloods.crowdmap.com/reports. Accessed 31 Jan 2013

Awange JL (2012) Environmental monitoring using GNSS. Springer, Berlin

Awange J, Kiema JBK (2013) Environmentea geoinformatics - monitoring and management. Springer, Heidelberg

Booth D, Haas H, McCabe F, Newcomer E, Ferris C, Orchard D (2004) Web services architecture. World Wide Web Consortium (W3C) Working Group

Craglia M, de Bie K, Jackson D, Pesaresi M, Remetey-Flpp G, Wang C, Annoni A, Bian L, Campbell F, Ehlers M, van Genderen J, Goodchild M, Guo H, Lewis A, Simpson R, Skidmore A, Woodgate P (2012) Digital earth 2020: towards the vision for the next decade. Int J Digit Earth 5(1):4–21

Fu P, Sun J (2011) Web GIS: principles and applications. ESRI Press, Redlands

Geoscience Australia (2012) Topographic mapping: mapconnect. Geoscience Australia, commonwealth of Australia. http://www.ga.gov.au/topographic-mapping/mapconnect.html. Accessed 29 Jan 2013. Geoscience Australia (2013) Earthquake Hazards 2012. http://www.ga.gov.au/darwin-view/hazards.xhtml. Accessed 29 Jan 2013

Goodchild MF, Guo H, Annoni A, Bian L, de Bie K, Campbell F, Craglia M, Ehlers M, van Genderen J, Jackson D, Lewis AJ, Pesaresic M, Remetey-Flppj G, Simpson R, Skidmore A, Wang C, Woodgate P (2012) Next-generation digital Earth. Proc Natl Acad Sci U S A 109(28):11088–11094

Government of Canada (2013) The atlas of Canada, Government of Canada. http://atlas.nrcan.gc.ca/site/english/toporama/index.html. Accessed 29 Jan 2013

Jones CB, Purves RS (2008) Web-based geographic information systems. In: Wilson JP, Fotheringham AS (eds) The handbook of geographic information science. Blackwell

Li S, Veenendaal B, Dragievi S, (2011) Advances, challenges and future directions in web-based GIS mapping services. In: Li S, Dragievi S, Veenendaal B (eds) Advances in web-based GIS. Mapping services and applications. Taylor & Francis Group, London. ISBN 978-0-415-80483-7

OGC (2013) Open Geospatial Consortium. http://www.opengeospatial.org. Accessed 29 Jan 13

Putz S (1994) Interactive information services using World-Wide Web hypertext. In: First international conference on the World-Wide Web, 25–27 May, Geneva, Published in Computer Networks and ISDN systems 27:(2) 273–280. Elsevier Science BV

Veenendaal B, Delfos J, Tan T (2011) Geolocating for web-based geospatial applications. In: Li S, Dragicevic S, Veenendaal B (eds), Advances in web-based GIS, mapping services and applications, CRC Press, Taylor & Francis Group, London. ISBN 978-0-415-80483-7

WA Atlas (2013) WA atlas. https://www2.landgate.wa.gov.au/bmvf/app/waatlas. Accessed 29 Jan 2013

Chapter 14
Geospatial in Support of EIA, SEA, and SA

This chapter has four broad sections. The first sections explains how geospatial tools and techniques can be used in support of environmental impact assessment (EIA) process, strategic environmental assessment (SEA), and sustainability assessment (SA). The second and third provide some examples of how geospatial tools (e.g., GIS, GNSS, etc.) have been used in various sites. Sections four and five explains the concept of strategic environmental assessment (SEA) and sustainability assessment (SA), using the example of Marillana Creek Mine. The last section concludes the chapter.

14.1 Role of Geospatial Techniques in EIA, SEA, and SA

14.1.1 EIA and the Need for Monitoring

Environmental Impact Assessment (EIA) is defined by Munn (1979) as the need to *identify* and *predict* the impact on the environment and on man's health and well-being of legislative proposals, policies, programs, projects, and operational procedures, and to interpret and communicate information about the impact. EIA is thus a process, a systematic process that examines the environmental consequence of development actions in advance (Glasson et al. 2005, p. 4). Glasson et al. (2005) have defined the purpose of EIA as an *aid to decision making*, *an aid to the formulation of the development actions*, and *an instrument to sustainable development*. In order to achieve these goals, EIA requires monitoring data that can be used to identify and predict impacts, and also to evaluate the impacts of a given project once approved. Whereas EIA has been traditionally restricted to projects that are deemed to have significant impacts on the environment, it has recently expanded to include *strategic environmental assessment* (SEA) discussed in Sect. 14.4 and *sustainability assessment* (SA) presented in Sect. 14.5.

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Environmental Science and Engineering, DOI 10.1007/978-3-319-27651-9_14

Monitoring involves the measuring and recording of physical, social, and economic variables associated with development impacts (see e.g., Awange 2012; Al-Rashdan et al. 1999). The activities seek to provide information on the characteristics and functioning of variables in *time*, *space*, and *scale* (discussed in Sect. 8.2), and in particular in the occurrence and magnitude of impacts (Glasson et al. 2005, p. 185). It offers the possibility of determining or assessing the extent of human impacts on the environment and also compares human impacts with natural variation in the environment. The advantages of monitoring following project implementations are that it can improve project management, it can be used as an early warning system to identify harmful trends in a locality before it is too late to take remedial action, it can help to identify and correct for unanticipated impacts, and it can also be used to provide acceptable data and information, which can be used in mediation between interested parties (Glasson et al. 2005, p. 185). Glasson et al. (2005, p. 186) defines environmental impact auditing as the comparison between the impacts predicted in *environmental impact statements (EIS)* and those occurring after implementation in order to assess whether the impact prediction performs satisfactorily. EIS is the document that contains the information and estimates of impacts derived from the various steps of the EIA process.

14.1.2 Applications of Geospatial Techniques

Global navigational satellite systems (GNSS; Awange 2012) discussed in Chap. 9 can be used to support the processes of project-based EIA, SEA and SA in provision of location-based data that support *monitoring* and *auditing*. As an example, in March of 2009, Kelly Core Salmon (KCS) Ltd filed an application with the Noca Scotia Department of Fisheries and Aquaculture (NSDFA) to relocate and expand the boundaries of the existing three aquaculture sites (Sand Point, Boston Rock, and Hartz Point) located in Shelburne Harbour, Nova Scotia (Sweeney International Management Corp 2009). The desire to relocate and expand was motivated by the need to improve the environmental performance of the three sites by allowing a greater flow and depth on the sites, easier access to the sites, and increased production, ensuring greater economic stability for KCS production in Nova Scotia (Sweeney International Management Corp 2009).

For the relocations and expansion to take place, EIA was undertaken in order to satisfy the criteria of the New Brunswick Department of Agriculture and Aquaculture (NBDAA), Nova Scotia Department of Agriculture and Aquaculture (NSDAA), and Fisheries & Oceans Canada (DFO) (Sweeney International Management Corp 2009). In support of provision of location-based data, GNSS was employed to provide the relocated boundary co-ordinates.

GNSS could also be useful in supporting impact assessments in the following ways:

(a) Provide location-based data useful in identification of features of interest, which could be impacted during the undertaking of the project-based EIA. For example, GNSS could be used to provide the locations of boreholes in a given region where a project that has the potential of contaminating groundwater has been proposed.
(b) Providing distance information that is useful in measuring access to infrastructure and social services such as health care. Gibson and McKenzie (2007) discuss how GNSS-based information on spatial distribution of population and services can lead to improved understanding of access to services. Understanding access to services is essential in spatial multi-criteria selection (e.g., Sect. 14.3.2), where a decision to choose an option from various alternatives is to be made. For instance, Perry and Gessler (2000) applies GNSS to measure access from communities to health-care facilities in Andean Bolivia, and used the results to propose an alternative model of health distribution in the study area.
(c) Its distance and travel time data can be useful in identifying barriers to the use of services (Gibson and MacKenzie 2007). Often, such hidden barriers can lead to poor decision leading to the selection of a given alternative at the expense of the other methods, which might be optional. Knowledge of these hidden barriers could thus enable policy and decision makers to make informed decisions.
(d) A combination of GNSS-based location data and geographical information system (see Chaps. 12 and 14 for more detail) would be very effective in illustrating access to services in a form that would be easily understood by the community during participatory stage of discussing environmental impact statement (EIS), and also for policy and decision makers during the selection of an option from given alternatives.
(e) In support of collection of socio-economic data, e.g., household surveys. Here, GNSS could be useful in improving the quality and cost-effectiveness of the survey data. GNSS locations could for instance be used to provide sampling boundaries as opposed to cases where such boundaries are arbitrarily selected or regular grids used where they are not useful (e.g., in monitoring variable features irregularly distributed over space such as air pollution). For example, Kumar (2007) show how a combination of GNSS and remote sensing was useful in drawing samples in a survey of 1,600 households spread across different air pollution zones in Delhi (India).
(f) For SEA and SA, GNSS can be of use in providing data for econometric modeling of casual impacts of policies (Gibson and MacKenzie 2007). In this regard, it could provide data that could enable practitioners to better control the geographical and regressional characteristic of their models, e.g., by comparing individuals who are subjected to a given policy and those who are not.
(g) Further, for SEA and SA, its integration with GIS can prove particularly useful in supporting the evaluation of cumulative impacts (see e.g., Sect. 14.4.1). This is achieved through the ability of GIS-GNSS to consider spatial component and allow the analysis of the temporal evolution, see, e.g., Smit and Spalding (1995).

14.2 Impact Monitoring to Detect Change

Impact monitoring focuses on identifying possible impacts of human activities on environment and to distinguish them from the non-human environmental processes, while *compliance monitoring* had the objective of supporting stipulated legislations that aim at protecting and conserving the environment. According to Downes et al. (2002), both compliance and impact assessments have a key objective of detecting change in selected variables, with impact assessment relying on comparisons within the collected data to assess whether an impact has occurred and the magnitude of such impact. Because impact assessment monitoring tend to be defined relative to natural conditions rather than being pegged to external criteria, Downes et al. (2002) propose a monitoring design model, which if properly implemented, could support *change detection*.

The model is location-based taking into consideration the fact that in most cases, variables are measured at a specific impact location or locations, i.e., the *impact location(s)*. They then argue that a change being monitored in a variable should be seen to have occurred by comparing the variable's status prior to the activity (baseline data), which they call "*Before*" and after or during the activity (operational data), which they call "*After*". This Before-After model takes place at the impact location. In order to distinguish between natural and impact induced changes, a location outside the activity (impact area) is suggested, i.e., the "*control*" upon which data is to be simultaneously sampled together with the impact location "before" and "after". This before and after, control and impact locations form the BACI (Before-After-Control-Impact) model. The model proceeds as follows (Downes et al. 2002):

- Data are collected at some ***impact locations*** over some period ***before*** the activity starts.
- Data are collected at some ***impact locations*** over some period ***after*** the activity starts.
- Data are collected at some ***control locations*** over the same period ***before*** the activity starts.
- Data are collected at some ***control locations*** over the same period ***after*** the activity starts.

In the BACI model above, the control location provides proxy data that are used to remotely sense the impact locations in the absence of a triggering activity. The assumption of the model is that if similar changes occur at both the control and impact locations, then the trigger for this changes would be natural causes since the control location does not have the activity. On the contrary, if the changes are only noticeable at the impact's location and not at the control location, then the activity at the impact location would be the most likely suspect. Because of the varying dynamics of the impacts and control locations, Downes et al. (2002) suggest that several control locations and possibly impact locations be used, thus extending the BACI model to MBACI model, where multiple locations are considered.

Within these BACI and MBACI models, GNSS could be useful in providing the positions of control and impact locations upon which environmental impact assessment monitoring could be collected simultaneously before and after the activity. Remote sensing could be employed to collect variable spatio-temporal data, with GIS being used to manage the various datasets, in addition to providing the platform for detecting the change being monitored.

Example 14.1 (Illustration of tourism impact on groundwater)
Consider that a particular hotel utilizes groundwater and due to increased number of tourists, plenty of water is used, and that the impact of groundwater abstraction on the hotel is to be monitored to avert the potential danger of the building collapsing. Using GNSS, coordinates of the hotel being monitored could be measured *before* it started operating to provide base data. During the operational phase, GNSS could be used to provide continuous coordinates of the building *after* the groundwater abstraction started. These observations are simultaneously observed to an established GNSS control points on stable locations some distance far away from the hotel both before, and after the groundwater abstraction started. The *relative positions* obtained will indicate the spatial variation of the hotel's position relative to the GNSS control (reference) before-and-after-the-impact. If no variation is noticed at the control location, but visible at the hotel (impact) location, then the variation could be attributed to groundwater abstraction. In such case, GNSS would have played a double role of providing locations of both impact (hotel) area and the control area, and also provision of time-variable data useful in generating relative motion (both horizontal and vertical) of the hotel useful in assessing the impact of groundwater abstraction.
♣ End of Example 14.1

14.3 Project EIA

14.3.1 Geospatial in Support of EIA Process

EIA generally goes through various stages, see e.g., Glasson et al. (2005, pp. 88–184) and Munier (2004, p.8). Some of these stages, and possible areas in which geospatial tools could be useful are discussed. The first of these stages is *screening*, where a project is assessed as to whether it requires EIA or not. Geographical Information System (GIS) discussed in Chap. 12 is the basic tool that could be employed to support screening in EIA. For example, in the work of Geneletti (2007), GIS was combined with a decision aiding tool known as Multi-criteria analysis (MCA) to produce thematic nature conservation layer maps used to support decisions on whether to undertake EIA for a proposed project and also to choose the most suitable locations for new projects in the alpine area located in Trentino (northern Italy). Antunes et al. (2001) propose a GIS approach for computing scores for criteria for use in MCA. Since GIS brings with it visual capability, its combination with MCA analytical tools will play a significant role in screening EIA projects as discussed in the next section. As a matter of fact, virtually all commercial GIS software in operation today have built and integrated MCA functionality into their systems.

The next stage of EIA after screening is the *scoping* stage, where the impacts and issues to be considered are identified. The process of scoping is that of deciding, from all of a projects possible impacts, and from all the alternatives that could be addressed, which ones are the most significant (Glasson et al. 2005, p.91). Identification of significant alternatives requires comparison to be made at the scoping phase. Usually, at the initial phase of scoping, a small number of alternatives will be selected for further analysis from many potential alternatives, and in the final evaluation, these alternatives are subjected to more detailed evaluation. An example is presented in the rare earth case where 15 sites were selected in the initial case from which 6 sites were chosen for further analysis (Ashton Mining Ltd 1991).

In evaluating possible alternatives, GIS is an attractive proposition given its ability to consider different factors within an integrated framework. In this respect, remote sensing could be employed to develop various factor maps. GNSS satellites could also play a vital role of not only providing the coordinates (i.e., positions) of alternative locations, but could be used to provide rapid field measurements of factors such as distances to environmental sensitive locations (e.g., groundwater or conservation parks), and the actual spatial coverage of areas of each alternative.

Example 14.2 (GNSS in support of choosing from alternative locations)

Consider Fig. 14.1 where three alternative perimeter locations are to be considered for the purpose of setting out a project such as sugar processing factory. *First*, the areas of these locations are to be established so that the smallest parcel of land is chosen to accommodate the factory and at the same time minimize on the land purchasing cost. *Second*, the distances of the sites to the nearest water source is required so as to assess the potential of the sugar factory contaminating the groundwater source. GNSS could be used to establish the corner positions of the various sites A, B, and C from which the perimeter and area of each parcel of the land could be rapidly calculated. Further, distances from each site to the nearest water source can rapidly be obtained in the field by measuring baselines of two receivers, one stationed at a given site and the other stationed at the water source as illustrated in Fig. 14.1. Another possibility would be to use a hand-held GNSS to obtain the direct distance measurements from each site to the water source using the navigation functions of these receivers by simply walking from the water source to the proposed sites. It is worth mentioning that these analyzes could be best undertaken within a GIS environment.

♣ End of Example 14.2

Analysis stage of EIA consists of *identification*, *prediction* and *evaluation* (Al-Rashdan et al. 1999). Impact identification brings together project characteristics and baseline environmental characteristics with the aim of ensuring that all the potential significant environmental impacts (adverse or favorable) are identified and

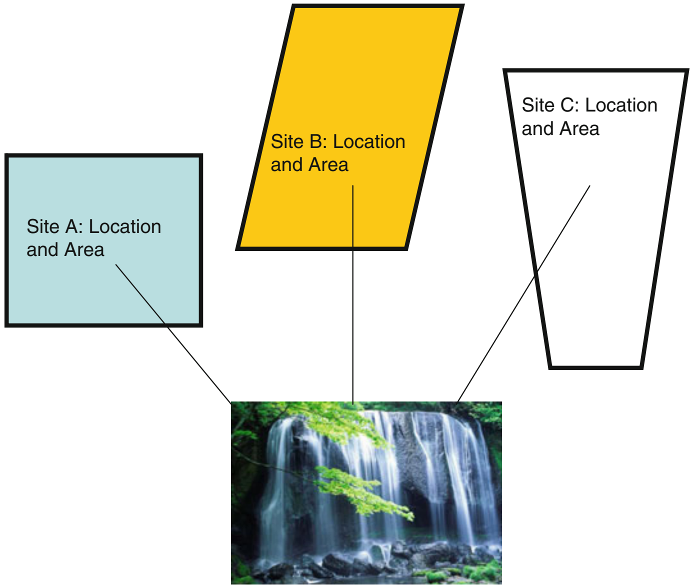

Fig. 14.1 GNSS support of site selection from three different alternatives. GNSS could be useful in providing positions, distances, perimeters and areas of each site, information that could aid decision markers choice of the correct site

taken into account during EIA process (Glasson et al. 2005, p.107). Remote sensing (i.e., Chap. 11), photogrammetry (i.e., Chap. 10) and GNSS could help in provision of environmental baseline data before the project is established. This could then be used in impact prediction which requires that it be based on available environmental baseline data and proper use of technology to identify environmental modification, forecast the quantity and/or *spatial dimension of change* in the environment, and estimation of the probability that the impact will occur (Al-Rashdan et al. 1999).

Techniques for impact identification and prediction are discussed, e.g., in Glasson et al. (2005, pp. 88–184). Several methods of impact identification exist and are generally divided into the following categories (Glasson et al. 2005, p.108); *checklist*, *matrices*, *quantitative methods*, *networks*, and *overlay maps*. These methods have been discussed in detail, e.g., by Shopley and Fuggle (1984) and Westman (1985). Incidentally, the last impact identification method i.e., overlay of maps provides spatial visualization and is best carried out within a GIS environment as discussed in Chap. 12. Evaluation in EIA looks mostly at the cost and benefits of a proposed project to the users, assesses the impact on environment, and compares various alternatives that will yield benefit of the project with minimum environmental and social impacts. Such alternatives could be evaluated through methods such as multi-criteria analysis (see Sect. 14.3.2). Remote sensing and GNSS satellites can play a vital role in this aspect of EIA with regard to documenting and identifying impacts associated with spatial changes. As illustrated in Fig. 14.1, GNSS could also assist in the determination of positions, distances, perimeters, and areas needed by decision makers to make informed choices.

14.3.2 Geospatial Technique and Multi-Criteria Analysis (MCA)

14.3.2.1 Spatial Multi-Criteria Analysis

The vast majority of environmental management decisions are guided by multiple stakeholders' interests. These decisions are often characterized by *multiple objectives*, *multiple alternatives* and *considerable uncertainties* (Gough and Ward 1996). Alternatives are means for accomplishing particular goals (Therivel 2004, pp. 109–110) and their evaluation is a requirement in EIA of some countries. For example, the *National Environmental Policy Act* (NEPA) 1969 (US) requires that alternatives be considered while undertaking EIA. When multiple stakeholders with varied interests are involved, and multiple objectives and alternatives have to be considered, the situation often turns out to be very complex. In such cases, *multi-criteria analysis* (MCA), a framework for evaluating decision alternatives against multiple objectives comes in handy. MCA is currently emerging as a popular approach for supporting multi-stakeholder environmental decisions as reported, e.g., in Regan et al. (2006).

MCA are methods that seek to allow for a pluralist view of society, composed of diverse stakeholders with diverse goals and with differing values concerning environmental changes (Glasson et al. 2005). According to Munier (2004, p. 132), MCA are tools that are used for the analysis of projects, plans, programmes and options either with single objective or with several objectives with many different attributes or criteria. Besides being a tool for aiding the selection of the best preferred alternative, Marttunen and Hamalainen (1995) suggests that it could also be used to increase the understanding of the problem by value structuring (i.e., identification of the objective and the analysis of values). The components of MCA are listed by Annandale and Lantzke (2000) as;

- a given set of alternatives,
- a set of criteria for comparing the alternatives, and
- a method for ranking the alternatives based on how well they satisfy the criteria.

Spatial multi-criteria decision problems typically involve a set of geographically-defined alternatives (events) from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria (Jankowski 1995; Malczewski 2006). For spatial multi-criteria decision analysis, two considerations that are of utmost importance are (Jankowski 1995; Carver 1991):

(1) A GIS component such as data acquisition, storage, retrieval, manipulation, and analysis capability, and

(2) spatial analysis component such as aggregation of spatial data and decision maker's preferences into discrete decision alternatives.

MCA can help decision makers to choose between several alternatives by comparing the advantages and disadvantages of each alternative, one against the other, see e.g., Janssen (2001). The significant advantage of most MCA methods as stated by Annandale and Lantzke (2000) is the capability to allow the evaluation criteria to be measured in either quantitative and/or qualitative terms, thus providing flexibility compared with other techniques such as cost-benefit analysis that require quantification of all values. Cost benefit analysis techniques are used, e.g., in economics to evaluate different alternatives, see e.g., Munier (2004, pp. 106–114).

There are several MCA techniques in operation in various countries, see e.g., Lahdelma et al. (2000), Munier (2004). Examples of these techniques include Analytical Hierarchy Process (AHP), Mathematical Programming (MP), Additive Weighting, and Concordance Analysis presented, e.g., in Annandale and Lantzke (2000), Munier (2004), Ministry of Environment and Energy, Government of Ontarion (1990). Malczewski (2006) conducted a survey of GIS-based multi-criteria decision analysis. A principled problem in choosing a decision aid method for a real-life problem is that, for the same data, different methods may produce different results (Lahdelma et al. 2000). This problem is further compounded by the difficulty of objectively identifying the best alternative or method in view of these differing results. In realization of this shortcoming, Lahdelma et al. (2000) lists the requirements of MCA methods for use in environmental problems as;

1. being well defined and easy to understand, particularly regarding the essential tasks such as setting of criteria and definition of weights,
2. being able to support the necessary number of decision makers,
3. being able to manage the necessary number of alternatives and criteria,
4. being able to handle the inaccurate or uncertain criteria information, and
5. due to time and money constraints, the need of preference information from the decision makers should be as small as possible.

Clearly, it is difficult to have a method that satisfies all these requirements. All MCA methods have their strengths and weaknesses. The Additive weighting and Concordance analysis presented in the Example of Sect. 14.3.2.3 fulfil requirements 1, 2 and 3.

MCA does not actually provide an absolute answer by specifying a particular alternative, instead, it provides a process that ranks various alternatives and leaves the final decision to the policy makers. On one hand, several studies indicate the success of MCA in ranking alternatives and therefore aiding in decision making, see e.g., Regan et al. (2006). On the other hand, researchers are still learning how it impacts on what could otherwise be an intuitive or ad-hoc group decision-making process (Hajikowicz 2007). As an example, Bojorquez-tapia et al. (2005) report that some researchers have found out that MCA can alienate decision makers or experts in multi-stakeholder problems due to its complexity and 'black box' nature.

To address the shortcoming of alienating stakeholders, who most often comprise of the community (e.g., conservation groups and people likely to be directly affected by the project), CWP (community weighting process) in MCA is currently gaining momentum as a possible solution that attempts to carter for the community's interests. The increasing role played by CWP in environmental decision making with MCA as a processing tool is captured, e.g., by Hajikowicz (2007) who states that the common reasons for applying MCA in multi-stakeholder decisions are to provide a transparent, structured, rigorous and objective evaluation of options.

Some examples of applications of MCA in EIA:
As already discussed, EIA processes involve several stages, see, e.g., in Glasson et al. (2005, pp. 88–184), and Munier (2004, p.8) many of which may utilize MCA. At the screening stage, for example, where a project is assessed whether or not it requires EIA, MCA could be used, e.g., where one alternative location is to be chosen from several, see, e.g., Kiker et al. (2005). The scoping stage of EIA is that of deciding, from all of a project's possible impacts, and from all the alternatives that could be addressed, which are the significant ones (Glasson et al. 2005, p.91). Identification of significant alternatives requires comparison to be made at the scoping phase. Usually, at the initial phase of scoping, a number of alternatives are selected for further analysis, and in the final stage, a small number of alternatives are chosen and subjected to more thorough evaluation. An example is provided by the EIA performed for Ashton Mining Ltd, which required a selection of the best location for iron ore processing from six possible locations (Ashton Mining Ltd 1991). MCA could be used in such scenario during scoping stage. This example is discussed further in Sect. 14.3.2.3.

Evaluation in EIA looks mostly at the cost and benefits of a proposed project to users, assesses the impacts on environment, and compares various alternatives that will yield benefits to the project, while at the same time minimizes environmental and social impacts. MCA plays a vital role in evaluation in EIA as exemplified in the work of Janssen (2001).

14.3.2.2 Decision Making and Alternatives

Steinemann (2001) considers alternatives as means to accomplish ends, and that from the perspective of EIA; these ends include not just a particular agency's goals, but also broader societal goals such as the *protection* and *promotion* of environmental quality. Steinemann (2001) further opines that developing the set of alternatives that become the choice set and the center of analyzes is the most important part of the EIA process. Decision makers can then chose from these choice sets rather than simply having to rubber stamp a proposal.

However, two problems that confront the development of alternatives are cited by Steinemann (2001). *First*, the public involvement often occurs too late to influence the development of the alternatives, and *second*, the alternatives are frequently eliminated from further consideration based on weak evaluations, which are not well-documented in the environmental impact statements (EISs). The first problem is associated with the very nature of project based EIA where the outcomes are almost always predetermined. In contrast to the project based EIA, SEA (Sect. 14.4) and SA (Sect. 14.5) enable earlier participation of the public. In evaluating alternatives, decision making is often based on some selected *criteria* and the desired objectives. Criteria are aggregate values computed from a much larger amount of so-called primary factors, which form the lowest level of information, also known as the assessment level (Lahdelma et al. 2000).

The problems with environmental decision making, however, are that they are intrinsically complex because they almost always involve many alternatives and multiple attributes (e.g., biological, economical, and social), the relative importance of which has to be determined by subjective evaluations (Marttunen and Haimailainen 1995). In an effective EIA process, alternatives will be sought that attempt to balance the data set with multiple attributes. The balancing act becomes even more crucial in SEA or SA where the desire is to balance the diverse ecological, social, and economic values over space, time and scale. These values are usually represented in the form of multiple criteria and *indicators* that sometimes express conflicting management objectives (Varma et al. 2000).

In SEA or SA, complex projects are often involved, which present many alternatives to choose from, necessitating the need for MCA for comparison. The situation is worsened when many stakeholders are involved and they conflict over the relative importance of the different comparison criteria. Annandale and Lantzke (2000) state that "when decisions become this complex, there is a need for special tools or techniques to help in making sense of what can be a large amount of information". In addition, complex environmental planning problems will almost always include value judgements, public opinion, and controversies. So, the techniques need to deal with more than just technical information (Annandale and Lantzke 2000).

In such complex situations, MCA provides the means for comparing the advantages and disadvantages of each alternative, one against the other. By doing this, decision makers are provided with the means of choosing between several alternatives (Janssen 2001). One of its advantages is that it permits public involvement in the process by allowing their voices to be heard through weighting of the criteria according to their preferences. Community weighting process (CWP) in MCA therefore leads to the community participating in decision making as already stated, and enhances public confidence in the final decision as opposed to where decisions are made using weak evaluation tools as already pointed out by Steinemann (2001). Its vital role is captured by Sheppard and Meitner (2005) who state that "public involvement needs more effective, defensible techniques usable by managers at the sharp end of decision making, rather than just in the scoping of public concerns and in setting broad strategies".

Specification of alternatives: Alternatives are different ways of achieving an objective. For example, if the objective is to find a suitable waste dumping site, the alternatives would be the various possible locations that can serve as dumping sites at a minimal cost and minimize environmental and social impacts. In real life, there will be, almost always, people with vested interest(s) in these locations, thereby complicating the task of objectively identifying a suitable site. Specification of alternatives is helpful in such situations as they account for as many of the stakeholder opinions as possible. Annandale and Lantzke (2000) suggest that the best approach in determining alternatives for a decision aiding exercise is the involvement of stakeholders and allowing them to offer as many alternatives as possible.

Specification of comparison criteria: In comparing alternatives, decision makers look for those alternatives that would be less costly in implementing but at the same time satisfy the environmental and social benefits. Criterion offers a possibility of comparing alternatives. Munier (2004, p. 48) defines criteria as parameters used to evaluate the contribution of a project to meet the required objectives. Desirable properties for criteria are presented, e.g., in Annandale and Lantzke (2000).

Scoring the alternatives: Annandale and Lantzke (2000) discuss the three types of measurement scales; *ordinal*, *interval*, and *ratio*. According to Annandale and Lantzke (2000) ordinal scales provide information on order only and are unsuitable for mathematical manipulations (addition, subtraction, multiplication and division). It can only indicate that one alternative scores higher than another alternative, but does not indicate by how much (i.e., magnitude). Ordinal scales favour qualitative attributes and are often used interchangeably with quantitative reserved for ratio or interval scales (Annandale and Lantzke 2000). The interval scale indicates the difference between two alternatives without giving the actual magnitude. Its advantage over the ordinal scale is that it permits addition and subtraction only. The ratio scale has a natural origin (zero value) and provides a measure of both difference and magnitude (Annandale and Lantzke 2000). It permits the mathematical operations and as such, favours scores obtained when the attributes are directly measured. Glasson et al. (2005) suggests that scoring may use qualitative or quantitative scales according to the availability of information. Both qualitative and quantitative scales could be used simultaneously as demonstrated in Annandale and Lantzke (2000).

Weighting the criteria: Commonly, in MCA methods, a number is assigned to each criterion describing its importance relative to other criteria. These numbers are called weights, and they model the decision maker's subjective preferences (Lahdelma et al. 2000). The interpretation of weights depends completely on the decision model used. Therefore, it is essential that the decision model be chosen prior to collecting weights, see e.g., Vincke (1992). The primary purpose of weighting the criteria is to develop a set of values, which indicate the relative importance of each criterion as valued by the community. These values are then used in ranking algorithms to determine the relative value of each alternative (Hajikowicz et al. 2000).

There are several ways of assigning weights. For example, weights could be assigned directly by the individuals undertaking the analysis to represent hypothetical point of view, or they could be based on the data collected from opinion polls, focus groups, public meetings or workshops, or other direct forms of sampling public or expert opinion (Annandale and Lantzke 2000; Lantzke 2006). Weights can also be assigned using some mathematical functions as indicated, e.g., in Munier (2004, p.53). This is therefore the part of MCA, which takes into consideration divergent views of stakeholders on a project.

This is captured by Glasson et al. (2005, p. 145) who states that MCA seeks to recognize plurality of views and their weights. Weights thus allow different views and their impacts on the final outcome to be expressed explicitly (Annandale and Lantzke 2000). Several techniques for weighting are presented in literatures, e.g., direct assessment and pair-wise comparison methods such as AHP, see e.g., Saaty (1980, 1987). In general, there exist no right weights that would allow comparisons between different alternatives. The weights obtained depend on the technique used (Lahdelma et al. 2000).

14.3.2.3 Application of Geospatial in Support of MCA

The following example illustrates how geospatial technique could be used together with MCA to assist in the selection of alternatives for sitting of the secondary processing plant of a high-grade rare earth's deposit at Mt. Weld reported in Ashton Mining Ltd (1991, 1992). This example uses both ratio and ordinal scales to score the alternatives relative to the criteria.

Background of the Mt. Weld project: In 1991, a two-year study program was undertaken by Ashton Mining Ltd (1991) to determine the feasibility of commercial development of a high-grade rare earth's deposit at Mt. Weld, near Laverton in the Eastern Goldfields in Western Australia. The project was to involve the mining and beneficiation of ores at Mt. Weld and the secondary processing of rare earth concentrates to produce rare earth chemicals at a site that was to be determined (Ashton Mining Ltd 1991). The evaluation of the sites was undertaken in two stages. In the first stage, 15 sites assessed to have the potential for the sitting of the secondary processing plant were evaluated. These were (Ashton Mining Ltd 1991): Collie, East Rockingham, Esperance, Kalgoorlie, Karratha, Kemerton, Koolyanobbing, Kwinana, Moore River, Mt. Weld, Muchea, Geraldton, Picton, Pinjarra and Northam in Western Australia.

Ashton Mining Ltd (1991) adopted *qualitative* and *semi-quantitative* approaches to compare each of the sites. The *semi-quantitative* method focused on the economic considerations, i.e., capital and operating costs, while the qualitative assessments included environmental considerations namely; public health, town planning, flora and fauna, and groundwater. It also included social considerations such as community infrastructure, availability of skilled labor, road and road-rail transport, and social acceptance.

Five appraisal categories adopted for each of the factors were; little or no constraint; manageable constraint, significant constraint, requiring detailed evaluation, and overriding constraint with the potential to preclude development. Out of the 15 sites, 6 (East Rockingharn, Collie, Kalgoorlie, Kemerton, Geraldton and Northam) were selected and subjected to further evaluation (Ashton Mining Ltd 1991).

The results of the second evaluation stage indicated *Northam* as the preferred site. Five alternative sites in the Northam region were then evaluated, and the proposed Meenaar Industrial Park was assessed as being the site with the greatest potential (Ashton Mining Ltd 1992). Between road only and road-rail options considered for transporting the ore concentration, residues and chemicals, the road option was preferred. The proposal was then submitted for environmental impact assessment (EIA) and was subjected to a public environmental review (PER) in 1992, see Ashton Mining Ltd (1991).

Now, let us apply two multi-criteria analysis (MCA) methods (*Additive weighting* and *Concordance analysis*) together with spatial tools, such as GIS and GNSS, to assist in the selection of alternatives and show that the same results, i.e., Northam could have been reached. Six alternative sites for the Mt. Weld EIA case study are evaluated using these MCA methods. For each of the 6 alternatives, 11 criteria were compared and scored using ratio and ordinal scales and processed.

Application of MCA:
Site Evaluation Criteria: In the site evaluation by Ashton Mining Ltd, a number of general and specific site requirements were identified and used to develop appropriate criteria which were applied to each site, see e.g., Ashton Mining Ltd (1991, pp. 24–25). The site evaluation criteria considered were those most suitable for the establishment of the secondary processing plant. Ashton Mining Ltd (1991) adopted *economic*, *environmental* and *social* criteria to evaluate the sites. In these criteria, which we discuss below, GNSS could play the role of providing site locations and the distances of various environmental features, e.g., groundwater source or community infrastructure from a given site.

The main economic criteria considered were to minimize the capital and operating cost to establish and operate the plant. Capital cost was needed for the construction of the secondary processing plant and to establish infrastructure (i.e., supplying power, water, natural gas and housing). Operating cost was to cover the cost of power, water, natural gas, land rates, transport of concentrates, residues, chemicals and products. All the assumptions made in calculating capital and operating costs are presented in Ashton Mining Ltd (1991, p. 52).

The environmental and social criteria adopted were those which minimized a site's potential for Ashton Mining Ltd (1991, p. 24);

- off-site effects on the public and to public health,
- conflict with surrounding (and future) land use,
- impact on the existing flora and fauna,
- impact on high-quality groundwater resources or other significant components of the physical environment, and
- inefficient utilization of land.

Social criteria were those which would ensure a site (Ashton Mining Ltd 1991, p. 25); is close to established and well developed community infrastructure, is near a suitably sized labor force with appropriate skills, minimizes the disruption and risks to the public from the transportation of materials, and is likely to be acceptable to the public. The assumptions made in deriving the environmental and social criteria are presented in Ashton Mining Ltd (1991, p.25). Both the environmental and social factors can be modeled in a GIS environment with appropriate cost layers developed for the different factors.

The results of the example when MCA was applied indicated both additive and concordance methods ranked Northam as the top site followed by East Rockingham, and demonstrated the suitability of Concordance analysis for evaluating alternatives when the criteria are scored using mixed ratio and ordinal scales, thus underscoring the usefulness of MCA in assisting decision makers to chose between alternatives during the evaluation process of environmental impact assessment (EIA). Care should however be taken to know the limitations of each method (e.g., Additive weighting), use proper weights, and agreeable threshold.

14.3.3 Example of Gnangara Mound Groundwater Resources

During 1992–1995, a review was undertaken in Western Australia on the proposed changes to environmental conditions of Gnangara Mound groundwater resources under Sect. 46 of the *Environmental Protection Act (EPA)* 1986 (WA). Using it as an example, a theoretical examination of the possible areas of EIA process that could have benefited from using geospatial tools is presented.

14.3.3.1 Background

The Gnangara Mound is Western Australia's largest source of groundwater, supplying up to 60 % of Perth's drinking water (Australian Water Resource 2005; Department of Water 2008). Its area is estimated to be 2,356 km^2 and comprises Gnangara, Yanchep, Wanneroo, Mirrabooka, Gwelup, Perth and Swan Groundwater Management Units (GMUs). Gnangara Mound supports local wetlands and lake ecosystems and supplies irrigation for horticulture and agriculture (Australian Water Resource 2005). It is also a major water source supporting a number of groundwater abstraction schemes operated by the Water Authority (1995). It is bounded to the north by Gingin Brook and Moore river, to the East by Ellen Brook, to the south by Swan River, and Indian Ocean to the West.[1]

Physical environment: Gnangara Mound is characterized by a hot dry summers and mild wet winters with an average annual rainfall of about 800 mm (Water Authority 1995). Department of Water (2007) gives an average annual value of 814 mm. The hottest month of the year is reported as February with an average maximum temperature of 34°, while August is the coldest month with an average maximum of 18° (Water Authority 1995). Water Authority (1995) state that the area does not have natural surface runoff due to the porous nature of soil in the area. Most of the water that falls as rainfall recharges the groundwater and that any surface water is due to discharge from groundwater. Recharge of groundwater depends largely on rainfall pattern, vegetation cover, and the water table.

Groundwater flows westerly from the top of the Mound following the terrain slope. Wetlands are generally found in the low areas where the water table reaches above the ground surface much of the year. Due to the presence and absence of water

[1] See, e.g., http://www.water.wa.gov.au/sites/gss/ggs.html.

above the ground in these wetlands, soil and vegetation have adopted to the pattern of groundwater. In general, groundwater quality is reported to be excellent (Water Authority 1995). It is however widely recognized that sustainability of the Mound as a water resource is under threat due to *climate change* and excessive drawing of water.

Biological environment: Water Authority (1995) reported the dominant terrestrial vegetation as the candle Banksia (*Banksia attenuate*) and firewood Banksia (*B. Mennziesii*). Vegetation of high significant conservation value was also reported in the area (Water Authority 1995). Vegetation, soils, and land forms of Gnangara have been mapped, e.g., in McArthur (1986). Fauna survey of 1977 and 1978 recorded 12 native mammals, 70 reptiles and amphibians and 223 bird species. Five caves out of the 273 documented caves in the Yanchep National Park were reported to be the most species rich subterranean ecosystem ever recorded, supporting 30 and 40 species compared to caves elsewhere in the world, which rarely have five animal species (Water Authority 1995). GNSS could be useful in providing the locations of these five caves.

Social environment: Water Authority (1995) reported a general increase in urbanization in the Gnangara Mound area that led to incremental approach to planning, subsequently having significant implications for the future of the area. Increase in urbanization comes along with changes in land use, which in turn impacts on the groundwater level. In the rural areas, common land uses reported at the time included market gardening and poultry farming. Specialized activities included flower, mushroom, and strawberry growing, and gourmet pheasant production, all of which required groundwater. Large areas of Gnangara Mound are State Forest under the management of Conservation and Land Management (CALM). Approximately 20,000 ha of this land was Pine plantation with the remainder of the State Forest being natural bushland (Water Authority 1995).

Water Authority (ibid) further reported 14 archaeological sites registered with the Western Australian Museum. Specifically, McNess, Lake Mariginiup, Lake Joondalup, Lake Goollelal, and Lake Gnangara among others were said to be sites of Aboriginal mythology and/or historical Aboriginal use. According to Water Authority (1995), it was also likely that most of the wetlands in the western linear wetland chain are potential areas of Aboriginal significance.

14.3.3.2 Review of Allocation and Management of Groundwater Resource

Under the guidance of the Environmental Protection Authority (EPA), Water Authority manages groundwater resources of the Mound. Private groundwater abstraction is managed through area allocation and licensing of users (Water Authority 1995). Water Resource Authority, therefore, has the task of ensuring that the environmental impacts from users and its own activities are minimized. This is achieved, e.g., through assessing the impacts of proposed land use changes on groundwater levels and in providing advice to land management and planning organizations. In 1986, Water Authority submitted the Gnangara Mound Water Resources Environmental Review and Management Program (ERMP) to Environmental Protection Authority (EPA) for;

(1) approval to develop the Pinjar Groundwater Scheme, and
(2) approval for changes to private groundwater allocations.

In 1988, the Minister of Environment approved development of Pinjar Stage 1 Groundwater Scheme and the changed private groundwater allocation quotas, subject to a number of environmental conditions (Water Authority 1995). The approval allowed for increased abstraction of groundwater by the Water Authority and other users. The conditions to be met included measures to protect the environment through; *Maintenance of water level in the wetlands*, *limits on private groundwater allocations*, *establishment of a management and monitoring program*, and *setting in place a range of administrative mechanism regarding inter agency interaction on groundwater management* (Water Authority 1995). In 1992, Water Authority identified the need to review the management of the southern portion of the Mound. Factors which necessitated the requirement for the review were Water Authority (1995);

- identification of other ecosystems, which had been, or had the potential of being affected by groundwater abstraction. These included shallow cave streams and phreatophytic vegetation,
- rapid increase in knowledge of Environmental Water Requirements (EWR), which suggested that water levels set by EPA in 1988 should be reviewed,
- increase in demand of groundwater by private users called for an assessment of the potential impacts that would result from further groundwater allocation,
- there was a need by Water Authority to further develop groundwater schemes (e.g., Pinjar Stages 2 and 3) on the Gnangara Mound and as such, a review of allocation and management was essential before development of the schemes could commence,
- the recognition that land use on the Mound could significantly affect groundwater availability required that the impacts of likely future land use scenarios be considered in allocating and managing groundwater, and
- since the outcome of the review was likely to involve changes in some of the environmental conditions, which applied to the management of Gnangara Mound, notably wetland water levels, allocation quotas and land use issues, consideration of any changes required the review to take the form of Environmental Impact Assessment (EIA).

A formal referral was submitted by Water Authority to the EPA[2] in late 1992, and it was decided that the conditions should be reviewed under Section 46 of the *Environmental Protection Act (EPA)* 1986 (WA). This then led to the review of allocation and management of groundwater resource by Water Authority. EPA guidelines for this review are presented in Water Authority (1995, Appendix 2).

[2]Environmental Protection Authority.

Focus of the environmental review: Environmental conditions reviewed focused on three main areas; *wetland water level*, *allocation quotas* and *land use issues*. EPA acknowledged that little information was available to determine EWR[3] for the wetlands and that there maybe changes to the set levels in future and required the initiation of research to provide an improved understanding of wetland ecology, which could then be used as a basis to review the wetland water level criteria.

With the continuing urban development in the Wanneroo region, evolving patterns of land use led to considerable changes in the pattern for demand for private water. Water demand in some areas, e.g., Flynn Drive could not be met. There was need to review groundwater availability with the view of allocating further resources to high demand areas. This could be achieved through further development of groundwater schemes within Gnangara Mound comprising Pinjar Stage 2 Part 1 groundwater scheme, which was scheduled for December 1996 and had been approved by EPA subject to the outcome of the allocation and management review.

Since also allocation of Pinjar Stage 2 Part 2 and Stage 3 groundwater schemes were being sought at the time, Water Authority believed in reviewing the allocation and management of water resource before further development of groundwater schemes so as to ensure equitable distribution between the public water supply and private use while minimizing environmental impacts.

14.3.3.3 Possible Geospatial Support of the Gnangara EIA

Impacts identification: Water Authority adopted the checklist method in identifying the impacts. This is the common procedure used in Western Australia where the proponent is required to complete a referral form (Department of Water 2007). In what follows, a network approach based on Sorensen (1971) and a GIS method are compared in order to demonstrate how application of geospatial technique could have been useful in enhancing impact identification.

The Sorensen Network Approach: Recreating the impacts in Water Authority (1995), first the activities to be undertaken in the Gnangara Mound review are specified. In this case, three major activities are identified from Water Authority (1995) as; *groundwater allocation*, *land use*, and *artificial maintenance of wetland's water levels*. Let us add rainfall to this list as a climate variable that has the potential of impacting on the water level. The causes of environmental changes associated with the activities above are then identified and a matrix format applied to trace its impact. In Fig. 14.2, use is made of the Sorensen (1971) principles to identify the impacts.

For instance, land use activity potentially results in clearing of vegetation, water abstraction, increase and decrease in density of pine plants, and climate change. These environmental changes, in turn, results in increased water level (e.g., when vegetation is cleared) as the primary effect. Increase in water level in turn leads to increased wetland vegetation areas and plant habitats, diversity of fauna, e.g., ducks and diving species, and improved water quality all of which are positive secondary

[3] Environmental water requirement.

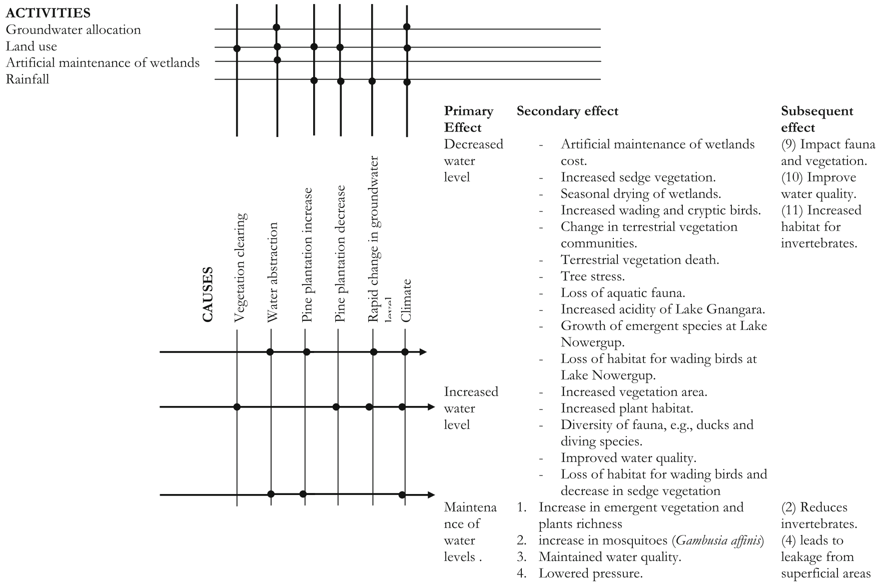

Fig. 14.2 Sorensen Network for Gnangara Mound impact identification

impacts. A negative secondary impact is the loss of habitat for wading bird species and sedge vegetation that rely on seasonal drying of the wetlands.

Water abstraction will occur when land use activities involve irrigation of farms, maintenance of golf course, and other uses which require water. This in turn leads to low wetland water levels as primary effects. Secondary effects as a result of the primary impact are presented in Fig. 14.2. All the potential impacts of land use can be traced in a similar way as demonstrated in Fig. 14.2. As demonstrated for the case of land use activity, the Sorensen network is used to identify the primary, secondary and subsequent impacts associated with the allocation of groundwater, artificial maintenance of wetlands and rainfall. Figure 14.2 summarizes the identified impacts using this method. It is evident that the identified impacts compare well with those reported in Water Authority (1995).

GIS Approach: For identification of environmental impacts having spatial distribution in nature, GIS with the assistance of GNSS satellites is an ideal tool. The potential of GIS in environmental impact assessments has been demonstrated, e.g., by Antunes et al. (2001) who applied it to evaluate the impacts of a proposed highway in Central Portugal. Antunes et al. (2001) suggested identification of environmental components (e.g., ecosystem) and receptors (e.g., a particular species likely to be affected by the component) using GIS. Another example of application of GIS to EIA is presented by Haklay et al. (1998) who advances a GIS-based scoping method and discusses the conditions necessary for its utilization.

For the Gnangara Mound example, the environmental components that were likely to be affected by groundwater allocation and management were *pine trees*, *vegetation*, and *wetlands*. Using Gnangara Mound Map of 1987 as a base for example, annual map layers of pine trees, vegetation, wetlands and urbanization can be overlaid on the base map in a GIS environment to produce a composite map, which can be used to identify hot spots (areas where land use are clearly identified to impact on wetland water levels and wetland vegetation). In this example, 1987 is selected as a base since environmental conditions issued by the Minister became operational in 1988. Annual groundwater level for specific wetlands are entered as attributes or produced in maps as contours. From the hot spots, areas and contours indicating water level changes and potential impacts can be identified. Where there is intense land use and sharp reduction in wetlands vegetation area, that specific land use could be said to impact on wetland water level, and subsequently vegetation. Linear trends can also be obtained on, e.g., the rate of pine growth/decline, vegetation clearing and urbanization by comparing annual values from 1997 to 1995. These could then be correlated with the groundwater levels to further identify the impacts. Negative linear trends will indicate adverse impact, while positive trend will indicate positive impact. Besides the trend analysis, visual examination of the layers could also indicate the spatial distribution. In this method, GNSS satellites provide location-based data to which the attributes, such as impacts on wetlands, are related.

Compared to the Sorensen method, the GIS approach has the advantage of being able to identify pertinent environmental effects on the basis of readily available information under stringent time and budget constraints (Haklay et al. 1998). Since it is best suited for *spatially distributed impacts*, it can analyze cumulative impacts better than the checklist or Sorensen network approach. It also provides friendly visual presentations, which are easily understandable by non-experts. Its drawbacks, however, are that it does not consider the likelihood of an impact, secondary impacts of the difference between reversible and irreversible effects (Glasson et al. 2005), and that it may require initial capital to establish.

Impacts prediction: Impact prediction requires that it be based on available environmental baseline data. In this example, the baseline data were readily available since regular water level monitoring had been taking place as part of the initial Ministerial conditions set out in 1988. Geospatial could have supported impact prediction of this EIA in several ways namely;

1. provision of baseline data,
2. using the GNSS technique to map boundaries of changing spatial features, e.g., wetland boundary changes as illustrated in Fig. 14.3, and
3. visualization of various “what if scenarios” that are likely to result from some prior conditions being fulfilled, e.g., understanding impact of drought. This can be implemented using GIS modeling techniques.

By having permanent reference marks set around the wells, GNSS satellite could be used to provide continuous measurements of positions and elevations of these reference marks. The measured depths of the wells could then be referred to these reference marks and thus help in monitoring the state of the groundwater levels (Fig. 14.3). This can be related to the state of vegetation and fauna. To predict the impacts of groundwater abstraction on wetlands and other vegetation, GNSS could

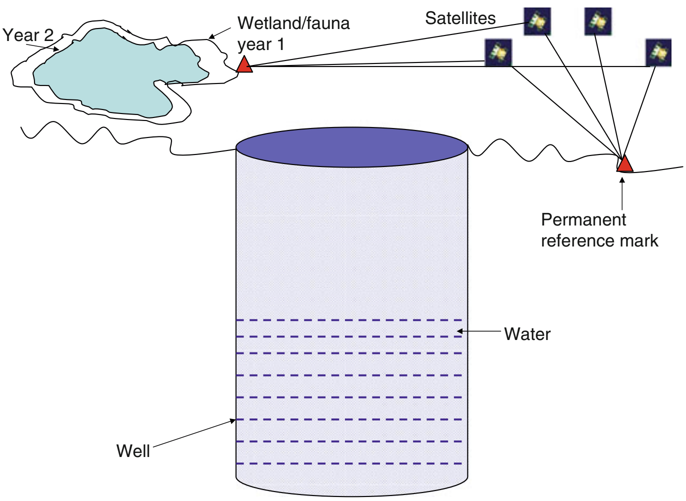

Fig. 14.3 GNSS monitoring of the impacts of well water abstraction using, e.g., spatial change maps of wetlands from years 1 to 2. Also, GNSS provides reference points upon which measured groundwater levels can be referenced

be used to document changes in the wetlands' boundaries (i.e., perimeters and areas, as illustrated in Fig. 14.3 for years 1 and 2). By analyzing annual trend of these boundary changes, it is possible to predict the impacts of groundwater abstraction on e.g., wetlands, assuming that the changes are unrelated, e.g., to evaporation. This will require some control location (see e.g., discussions on BACI model in Sect. 14.2).

Impacts of groundwater variation on terrestrial vegetation were reported by Mattiske (1994) as ranging from small change in community structure in favour of more drought tolerant species, through to deaths of Banksia woodland vegetation. Indeed, that the death of Banksia vegetation were triggered by groundwater variation was supported by the findings of Water Authority (1992), which suggested that Banksia trees that occurred where depth to groundwater was less than 6 m were most vulnerable to groundwater reduction. The study further suggested a general stress on vegetation due to reduced groundwater level.

Groom et al. (2000) deduced that a lowering of groundwater level by 2.2 m at a station P50 between the summers of 1990 and 1991, resulting from the cumulative effects of abstraction and below average annual rainfall (low groundwater recharge), coincided with a loss of between 20 and 80 % of mature Banksia species within 200 m of the bore. Over a similar time period, no significant decreases in the abundance of species were recorded in the monitored site to have been influenced by groundwater abstraction. They concluded that negative impact of groundwater draw-down on Banksia populations made it an important indicator of decreasing groundwater levels on the Gnangara groundwater Mound. GNSS monitoring of groundwater abstraction (Fig. 14.3) therefore could be useful in predicting impact on Banksia trees if the proposed changes in environmental condition would impact on groundwater by similar level, i.e., lowering of groundwater level by more than 2.2 m.

Geneletti (2007) demonstrates the capability of using GIS method to compute spatial indicators to predict and quantify critical impacts, such as ecosystem loss and fragmentation, soil erosion, geomorphologic hazards, interference with flora and fauna, and visibility. Since GIS has successfully been used by Geneletti (2007), it could be applied together with GNSS to predict variation in spatial distribution of environmental components caused by groundwater level variation.

Once groundwater changes have been obtained using, e.g., piezometric readings, and boundaries of impacted features (e.g., wetland in Fig. 14.3) mapped using GNSS, overlaying the land use and vegetation cover maps could then be performed using GIS for the same time period. Correlation between the land use, terrestrial vegetation and groundwater level could then be developed and predictions made on the impact of land use and terrestrial vegetation on groundwater level, and impacts of groundwater level on wetland vegetation. Linear and cyclic trends analysis could then be developed to give predictions at various temporal resolutions.

To support the prediction of impact of groundwater abstraction on fauna in caves, hand-held GNSS receivers can be used to provide locations of these caves, which can be related to groundwater level. Jasinska and Knott (1991) listed about 100 caves in Yanchep National Park and reported that little information was known about the biology of the aquatic fauna within these caves. They found aquatic species of high conservation value and concluded that one of the greatest threats to these species would be the permanent or temporary drying of the caves streams in which they occur. Since these aquatic fauna are of high conservation value, they could be seriously affected by drying of the streams within the cave to a point of extinction. GNSS could be useful in the prediction of the effect of regional warming on groundwater through the analysis of the GNSS derived tropopause heights as discussed in Awange (2012).

Comparison of the prediction methods: The model based approach adopted by the Water Authority (1995) is the most commonly used method in most EIA of groundwater impacts. Models rely on the input data and the assumptions that are taken into consideration. The more they fit in the model, the more reliable are the output. The disadvantage of using models, however, is that they require some expert knowledge during their development and operation stages. Any wrong assumptions, input data, and usage can lead to false information and interpretation.

The Field experiment using GNSS and GIS has the advantage of using real data in their predictions as opposed to simulated values as is the case of models. They also provide easy visual interpretation of the results. The disadvantage is that it comes at a cost. The initial cost of installing a GIS may be high. Besides, there is the cost of validating the data using GNSS. Another disadvantage is the incapability to predict higher order impacts. In the Gnangara Mound example, it was difficult to use GNSS and GIS to predict the impacts of variation of wetland vegetation to fauna which may require other methods for enhancement.

In summarizing this example, in identifying and predicting the impacts for Gnangara Mound using alternative GIS-based methods to those adopted in the Water

Authority (1995), it has been pointed out that identification and prediction models are labor intensive and require knowledge of the system. More often, they are based on assumptions, which may not fit the model leading to delivery of meaningless results. Field experiments, though straight forward, requires some validation, which may increase the cost of EIA. Finally, baseline environmental parameters should be established upon which judgment of an impact can be made. Identification method should be a combination of methods that are simple to use, but which are capable of identifying higher order impacts and their inter-relations. Where models are adopted, they should be well understood by the analyst and assumptions must be clear and meaningful.

In particular, when used in conjunction with GIS and field data from the GNSS, a suitable approach for identifying and predicting impacts, which are spatially distributed could be obtained. This example indicates the possibilities of geospatial techniques to support identification and prediction of environmental impacts associated with the proposed change in environmental conditions of Gnangara Mound and highlight the limitations of the methods.

14.4 Strategic Environmental Assessment (SEA)

SEA is the process that aims at integrating environmental and sustainability considerations in strategic decision-making (Therivel 2004). In so doing, the goal is to protect the environment and promote sustainability. Sadler and Verheem (1996) define SEA as a systematic process for evaluating the environmental consequences of a proposed policy, plan or program initiative in order to ensure that they are fully included and appropriately addressed at the earliest appropriate stage of decision making at par with economic and social considerations. Wood and Djeddour (1991) define a policy as inspirational and guidance for action, a plan as a set of coordinated and timed objectives for the implementation of the policy, and a programme as a set of projects in a given area, see also Therivel (2004, p. 12).

The basic principles of SEA have been presented, e.g., by Therivel (2004) as being a tool for improving the strategic actions, promoting participation of stakeholders in decision making process, focusing on key environmental/sustainability constraints, identifying the best option; minimizing negative impacts, optimizing positive ones, and compensating for the loss of valuable features and benefits; and ensuring that strategic actions do not exceed limits beyond which irreversible damage from impacts may occur. Its advantages include (Therivel 2004);

(1) being able to shape the projects at an earlier stage through the appraisal of strategic action. This offers the chance to influence the kinds of projects that are going to happen, not just the details after the projects are already being considered,

(2) SEA deals with impacts that are difficult to consider at project level. It deals with *cumulative* and *synergistic* impacts of multiple projects, e.g., cumulative impacts of various mining sites on the development of an entire area,
(3) SEA can deal with large-scale environmental impact such as those of biodiversity or global warming more effectively than individual EIA,
(4) unlike project based EIA which formulate goals around an already selected approach, SEA promotes better consideration of alternatives, thereby ensuring a strategic approach to action,
(5) it incorporates environmental and sustainability consideration in decision making thus adding an additional dimension to decision making,
(6) it enables public participation in decision making thus making the whole process inclusive and transparent, and
(7) it has the potential to promote streamlined decision making.

SEA has also benefited from MCA as illustrated by Noble (2002) who presents five scenarios that were evaluated within SEA to determine the most suitable option for power generation to be developed to cover the Canadian need up to the year 2050. The role and contribution of geospatial in supporting global warming monitoring is treated in Awange (2012). In what follows, the cumulative impact aspect of SEA and the possible role and contribution of geospatial is discussed.

14.4.1 Geospatial and Cumulative Impacts Assessments

Cumulative effects refer to the phenomenon of *temporal* and *spatial* accumulation of change in environmental systems in an additive or interactive manner and may originate from either an individual activity that recurs with time and is spatially dispersed, or *multiple activities* (independent or related) with sufficient spatial and temporal linkage for accumulation to result (Spaling and Smit 1993). The attributes of cumulative effects are classified by Spaling and Smit (1993) into three categories; temporal accumulation, which occurs if the interval between perturbation is less than the time required for an environmental system to recover from each perturbation, *spatial accumulation, which results where spatial proximity between perturbation is smaller than the distance required to remove or disperse each perturbation*, and the nature of human induced activities or perturbations, which also affect accumulation of environmental change provided the perturbations are sufficiently linked in time, space, and scale.

Cumulative impact assessment is thus defined by the Commonwealth Environmental Protection Agency (1994) as predicting and assessing all other likely existing, past and reasonable foreseeable future effects on the environment arising from perturbations. In some legislations, e.g., in Canada, EIA regime has made it specific and mandatory, where consideration of cumulative effects assessment has been made explicit and mandatory both federally and in several provinces (Glasson et al. 2005). In USA, *National Environmental Policy Act* (1967) requires the assessment of cumulative impacts, while in Australia, assessments have largely been carried out by regulatory authorities, rather than project proponents. In Western Australia for example, the EIA process does not come out forcefully on cumulative impacts assessment.

Spaling and Smit (1993) provide an in-depth look at the contributions and shortcomings of EIA to assessing cumulative impacts. Three key factors in favor of EIA are theoretical understanding of environmental change through empirical analysis and modeling of responses of environmental systems through human induced perturbations, the development of various analysis methods for projecting and assessing the various environmental changes associated with the proposed human activities, and regulatory and administrative mechanism contributed by EIA in the integration of environmental consideration in decision making. In EIA, cumulative impacts can be identified at the *scoping stage*, where issues to be examined are pruned. It is at this stage where the spatial and temporal effects of cumulative impacts can be considered (Scace 2000).

Geospatial could be useful in *providing the locations of multiple activities*, *mapping the changes in spatial coverage*, and *monitoring variation in groundwater* as a result of cumulative impacts.

14.4.2 Example of Marillana Creek (Yandi) Mine

Background: Marillana Creek (Yandi) Mine operated by BHP Billiton Ore Pty Ltd (BHPBIO) is located approximately 90 km north-west of Newman in the Pilbara region of Western Australia (BHP Billiton Iron Ore Pty Ltd 2005). The mine is situated within lease ML 270SA, and is operated under the Iron Ore (Marilliana Creek) Agreement Act 1991 (BHP Billiton Iron Ore Pty Ltd 2005). BHPBIO also has a smaller lease (M 47/292) located to the immediate north of ML 270SA. The Yandi ore body occurs within an ancient channel iron deposit (CID). This deposit is subdivided into a series of mine areas, i.e., central pits (C1 to C5), eastern pits (E1 to E8), and the western mesa pits (W1 to W6) (BHP Billiton Iron Ore Pty Ltd 2005). The CID is about 80 m thick and the majority of mining is within the upper 60 m. BHPBIO (referred to as proponent in this example) operates dewatering bores that lower the water table in the vicinity of each pit by approximately 30 m (BHP Billiton Iron Ore Pty Ltd 2005).

In May 1988, an approval was granted by the Minister for Environment to mine E2 and C5 at a rate of 5 million tonnes per annum (EPA 1988) and in 1991, mining commenced. In 1992, 1994 and 1995, EPA assessed modifications to the original proposal, which involved increased rates of production and mining of additional pits (EPA 1992, 1994, 1995). At the time of application for approval by the proponents, mining was taking place in the E2, C1/C2 and C5 areas. In 2004, the proponent sought approval under Part IV of the *Environmental Protection Act* (WA) 1986 to concurrently mine from pits across the leases (ML 270SA and M 47/292), and in addition update, assess, and agree on closure concepts for the whole of the deposit.

During the mining of individual pits, the proponents proposed to partially fill the voids with overburden (waste) material from other pits, and to use the same open cut mining techniques and ore processing methods over the remaining life of the mine (BHP Billiton Iron Ore Pty Ltd 2005). The agreed concepts were to be documented through closure specific conditions that were issued by the Minister of Environment. The project was called the Marillana Creek (Yandi) Life of Mine and was expected to deliver 40 million tonnes per annum with a lifespan of 30 years (BHP Billiton Iron Ore Pty Ltd 2005).

The expansion of delivery capacity from an initial 5 million tonnes per annum to 40 million tonnes per annum resulting from concurrent pit mining had the potential to *significantly impact* on the environment. Besides, Hamersley Iron also holds a mining lease (274SA) over the CID, east of BHPBIO's lease, and was mining up to 34 million tonnes per annum at the same time. The potential impact on environment, therefore, was not only likely to come from the proposed project but also *cumulative* taking Hamersley into consideration. Thus, there existed a need for EIA under Part IV of the *Environmental Protection Act (EPA) 1986* (WA).

BHPBIO (BHP Billiton Iron Ore Pty Ltd 2005) produced an EIS[4] that documented the environmental objectives, potential impacts, proposed environmental management measures and predicted outcomes. Environmental Management Plan and Decommissioning and Final Rehabilitation Plan were also presented as key supportive documents to the Environmental Protection Statement (EPS). EPA was advised of the proposal in January 2004 and based on the information provided, considered that the proposal had the potential to impact on the environment, but could be managed to meet the EPA's environmental objectives (EPA (Environmental Protection Authority) 2005). Consequently, EPA determined, under section 40(1) of the *EPA* 1986 (WA), that the level of assessment for the proposal was EPS.[5] EPA's advice and recommendations were then forwarded to the Minister of Environment in accordance with section 44(1) of *EPA* 1986 (WA) EPA (Environmental Protection Authority) (2005). The Minister of Environment granted approval with a set of conditions on 6th of July 2005.

Cumulative impacts: Since the EPS proposed to concurrently mine the pits within the leases as opposed to the previous pit by pit mining, there existed a potential to lead to *cumulative impacts* as discussed in Spaling and Smit (1993). Cumulative impacts were likely to be felt on the surface and groundwater. As part of the effort to manage cumulative effects accrued from surface water, the proponent proposed to integrate the surface water monitoring program to a wider monitoring initiative in the Marillana Creek catchment. This was to be achieved by adding flow gauge stations on the Marillana Creek and its tributaries within, upstream, and downstream of ML 270SA and 47/292 (BHP Billiton Iron Ore Pty Ltd 2005).

On groundwater resource, BHPBIO (BHP Billiton Iron Ore Pty Ltd 2005) identified the potential of cumulative impacts given the presence of Hamersly Iron operation in the neighborhood. The proponents took into account the impacts in their

[4]Environmental impact statements (EIA).

[5]Environmental protection statement.

regional groundwater model and de-watering license. Both surface and groundwater monitoring to be undertaken by the proponents during mining was expected to provide a mechanism for monitoring cumulative impacts (BHP Billiton Iron Ore Pty Ltd 2005). GNSS could play a role in providing location-based information on test sites (flow gauge station) and also provide perimeter/area information that could help in monitoring of the cumulative impacts in the entire mining region (e.g., Fig. 14.3). This information could be integrated with a GIS to support management decisions.

14.5 Sustainability Assessment

Sustainability has been defined as meeting the needs of current and future generations through integration of environmental protection, social advancement, and economic prosperity (Government of Western Australia 2003). Sustainability assessment (SA) can be performed when a proponent requests a regulator to do so (external) for the purpose of approval or internally as a mechanism for improving internal decision-making and the overall sustainability of the final proposal, see e.g., Pope (2006), Pope and Grace (2006).

Pope et al. (2004, 2005) classify SA into objective-led (strategic) and EIA based (narrow) approaches. Morrison-Saunders and Therivel (2006) rank the various SA approaches with the EIA-led approach on bottom and the integrated (objective-led) approach at the top, see also Hacking and Guthrie (2008). Between them are various approaches, e.g., the win-win-win. Citing the dangers inherent in using the separate findings of the three sustainability pillars (environment, social, and economics) at the decision stage, Gibson (2006) proposes adoption of an integrated approach. Caution should, however, be observed when using the term “integration” as it is used variedly by different authors, see e.g., Lee (2006), Morrison-Saunders and Therivel (2006).

SA involves (i) *Sustainable decision making protocol*. A sustainable decision making protocol is a process of setting objectives, criteria, and targets that underpin SA. Hacking and Guthrie (2006) present several sources of sustainability development objectives and propose the use of threshold as one of the means, (ii) *alternative approaches*, which are options, choices, or courses of action. They are means to accomplish particular goals (Steinemann 2001). Alternatives have been shown to be affected by the formulation of the decision question. SA, similar to SEA, has also benefited from MCA. In the province of Reggio Emilia (Northern Italy), Ferrarini et al. (2001) used MCA to rank 45 municipalities based on 25 state of the environment indicators. Their results provided information on the state of sustainability in the province as a whole. GIS could support SA in choosing the best alternative as already discussed in Sect. 14.3.2.2.

14.6 Concluding Remarks

The use of GIS to support impacts' assessment is still developing and certainly that of GNSS is a new concept. This chapter attempted to motivate EIA, SEA and SA experts dealing with impact assessments to exploit the full potential of GNSS, especially with regard to its superb provision of location-based information and measurement of spatial variations. GNSS satellites could for example be used to provide information related to distances, e.g., distances of the alternative sites from established and well developed community infrastructures. The distances can readily be computed and incorporated into the MCA criteria and used to compute the desirable alternative that will inform decision making. GNSS could also be useful in providing information on spatial coverage of the proposed sites and also in environmental audit to evaluate compliance where location and spatial variation data are required. GNSS data together with remote sensing data can then be integrated in GIS to support the EIA process as discussed in the chapter.

References

Al-Rashdan D, Al-Kloub B, Dean A, Al-Shemmeri T (1999) Environmental impact assessment and ranking the environmental projects in Jordan. Eur J Oper Res 118:30–45. doi:10.1016/S0377-2217(97)00079-9

Annandale D, Lantzke R (2000) Making good decisions: a guide to using decision-aiding techniques in waste facility siting. Institute for Environmental Science, Murdoch University, Perth

Antunes P, Santos R, Jorda OL (2001) The application of geographical information systems to determine environmental impact significance. Environ Impact Assess Rev 21:511–535

Ashton Mining Ltd. (1991) Mt Weld rare earths project: sites evaluation study for a rare earths secondary processing plant, report prepared by Kinhill Engineers

Ashton Mining Ltd. (1992) Mt Weld rare earths project: public environmental review, report prepared by Kinhill Engineers

Australian Water Resource (2005) Combined water management area: Gnangara Mound. http://www.water.gov.au/RegionalWaterResourcesAssessments/SpecificGeographicRegion/TabbedReports.aspx?PID=WA_GW_51x. Accessed 8 March 2008

Awange JL (2012) Environmental monitoring using GNSS. Springer, Berlin, New York

Awange JL, Kiema JBK (2013) Environmental geoinformatics, monitoring and management. Springer, Berlin, New York

BHP Billiton Iron Ore Pty Ltd (2005) Marillana Creek (Yandi) Mine—Environmental Management Plan, Revision 3

Bojorquez-tapia LA, Sanchez-colon S, Martinez AF (2005) Building consensus in environmental impact assessment through multicriteria modeling and sensitivity analysis. Environ Manag 36:469–481

Carver SJ (1991) Integrating multi-criteria evaluation with geographical information systems. Int J Geogr Inf Syst 5(3):321–339. doi:10.1080/02693799108927858

Commonwealth Environmental Protection Agency (1994) Review of Commonwealth environmental impact assessment. Canberra: CEPA 10

Department of Water (2007) Environmental Management of Groundwater Abstraction from the Gnangara roundwater Mound 2004–05, annual compliance report to the Environmental Protection Authority, July 2004 to June 2005

Department of Water (2008) Gnangara Mound—a unique water resource. http://portal.water.wa.gov.au/portal/page/portal/WaterManagement/Groundwater/Gnangara/. Accessed 14 March 2008

Downes BJ, Barmuta LA, Fairweather PG, Faith DP, Keough MJ, Lake PS, Mapstone BD, Quinn GP (2002) Monitoring ecological impacts: concepts and practise in flowing waters. Cambridge University Press, Cambridge

EPA (1992) Yandicoogina (Marillana) iron ore project—change of ministerial condition due to increase in rate of production, Report and Recommendations of the Environmental Protection Authority, Bulletin 622. Environmental Protection Authority, Perth

EPA (1994) Yandicoogina (Marillana) iron ore project—change of environmental conditions due to increase in rate of production, Report and Recommendations of the Environmental Protection Authority, Bulletin 738. Environmental Protection Authority, Perth

EPA (1995) Duplication of iron ore mining operation, Yandi mine ML 270SA, Hamersley Range, 90 km north west of Newman, Report and Recommendations of the Environmental Protection Authority, Bulletin 802. Environmental Protection Authority, Perth

EPA (1988) Yandicoogina (Marillana) iron ore project, Report and Recommendations of the Environmental Protection Authority, Bulletin 323. Environmental Protection Authority, Perth

EPA (Environmental Protection Authority) (2005) Marillana Creek (Yandi) Mine Life of Mine proposal, mining leases 270SA and 47/292, 90 km north-west of Newman. Report and recommendation of the EPA, assessment no 1555, Bulletin 1166. Perth, WA

Ferrarini A, Bodini A, Becchi M (2001) Environmental quality and sustainability in the province of Reggio Emilia (Italy): using multi-criteria analysis to assess and compare municipal performance. J Environ Manag 63:117–131. doi:10.1006/jema.2001.0465

Geneletti D (2007) An approach based on spatial multicriteria analysis to map the nature conservation value of agricultural land. J Environ Manag 83:228–235

Gibson R (2006) Beyond the pillars: sustainability assessment as a framework for effective integration of social, economic and ecological considerations in significant decision-making. J Environ Assess Policy Manag 8(3):259–280. doi:10.1142/S1464333206002517

Gibson J, MacKenzie D (2007) Using global positioning systems in household surveys for better economics and better policy. World Bank Res Obs 22(2):217–241. doi:10.1093/wbro/lkm009

Glasson J, Therivel R, Chadwick A (2005) Introduction to environmental impact assessment, 3rd edn. Routledge, New York

Gough JD, Ward JC (1996) Environmental decision making and land management. J Environ Manag 48(1):1–15

Government of Western Australia (2003), Hope for the Future: The Western Australian State Sustainability Strategy. Department of the Premier and Cabinet Perth, Western Australia. http://www.sustainability.dpc.wa.gov.au/docs/Final%20Strategy/SSSFinal.pdf. Accessed 2 March 2008

Groom BPK, Froend RH, Mattiske EM (2000) Impact of groundwater abstraction on woodland, Swan Coastal Plain, WA. Ecol Manag Restor 1:117–124

Hacking T, Guthrie P (2006) Sustainable development objectives in impact assessment: why are they needed and where do they come from? J Environ Assess Policy Manag 8(3):341–371. doi:10.1142/S1464333206002554

Hacking T, Guthrie P (2008) A framework for clarifying the meaning of triple bottom-line, integrated, and sustainability assessment. Environ Impact Assess Rev 28(2–3):73–89. doi:10.1016/j.eiar.2007.03.002

Hajikowicz SA (2007) Supporting multi-stakeholder environmental decisions. J Environ Manag 88:607–614. doi:10.1016/j.jenvman.2007.03.020

Hajikowicz SA, McDonald GT, Smith PN (2000) An evaluation of multiple objective decision support weighting technique in natural resource management. J Environ Plan Manag 43(4):505–518

Haklay M, Feitelson E, Doytsher Y (1998) The potential of a GIS-based scoping system: an isreali proposal and case study. Environ Impact Assess Rev 18:439–459

Jankowski P (1995) Integrating geographical information systems and multiple criteriadecision making methods. Int J Geogr Inf Syst 9(3):251–273

Janssen R (2001) On the use of multi-criteria analysis in environmental impact assessment in the Netherlands. J Multi-Criteria Decision Anal 10:101–109

Jasinska EJ, Knott B (1991) Stability of root mat ecosystem in groundwater stream: Cabaret cave. University of Western Australia, Yanchep National Park, WA

Kiker GA, Bridges TS, Varghese A, Seager TP, Linkov I (2005) Application of multicriteria decision analysis in environmental decision making. Integr Environ Assess Manag 1(2):95–108. doi:10.1897/IEAM_2004a-015.1

Kumar N (2007) Spatial sampling for collecting demographic data. Paper presented at the annual meeting of the population association of America, New York, March 29–31

Lahdelma R, Salminen P, Hokkanen J (2000) Using multicriteria methods in environmental planning and management. Environ Manag 26:595–605

Lantzke R (2006) MCA: the weighting process and overall comments on a weighting process. Environmental Science, Murdoch University. Unpublished. http://lms.murdoch.edu.au/webct/urw/lc152224987001.tp152225013001/RelativeResourceManager/Template/content/10_13evaluation/three-mca-wt-mthds.pdf. Accessed 15 April 2008

Lee M (2006) Bridging the gap between theory and practise in integrated assessment. Environ Impact Assess Rev 28:57–78. doi:10.1016/j.eiar.2005.01.001

Malczewski J (2006) GIS-based multicriteria decision analysis: a survey of the literature. Int J Geogr Inf Sci 20(7):249–268

Marttunen M, Haimailaiinen RP (1995) Decision analysis interviews in environmental impact assessment. European J Oper Res 87:551–563

Mattiske EM (1994) Monitoring the effects of groundwater extraction on native vegetation on the Nortrhern Swan Coastal Plain. EM Mattiske and associates, Western Australia

McArthur WM (1986) The Gnangara Mound landforms, soils and vegetation. Gnangara Mound Environmental Review and Management Programme, Water Authority WA

Ministry of Environment and Energy, Government of Ontarion (1990) Evaluation methods in environmental assessment, pp. 3–12, 33–51, 112–137

Morrison-Saunders A, Therivel R (2006) Sustainability integration and assessment. J Environ Assess Policy Manag 8(3):281–298. doi:10.1142/S1464333206002529

Munier N (2004) Multicriteria environmental assessment. A practical guide. Kluwer Academic Publishers, Dordrecht

Munn RE (1979) Environmental impact assessment: principles and procedures, 2nd edn. Wiley, New York

Noble B (2002) Strategic environmental assessment of Canadian energy policy. Impact Assess Project Apprais 20(3):177–188. doi:10.3152/147154602781766681

Perry B, Gessler W (2000) Physical access to primary health care in Andean Bolivia. Soc Sci Med 50(9):1177–1188. doi:10.1016/S0277-9536(99)00364-0

Pope J (2006) What's so special about sustainability assessment? J Environ Assess Policy Manag 8:v–x. doi:10.1142/S1464333206002505

Pope J, Grace W (2006) Sustainability assessment in context: Issues of process, policy, and governance. J Environ Assess Policy Manag 8:373–398. doi:10.1142/S1464333206002566

Pope J, Annandale D, Morrison-Saunders A (2004) Conceptualizing sustainability assessment. Environ Impact Assess Rev 24:595–616. doi:10.1016/j.eiar.2004.03.001

Pope J, Annandale D, Morrison-Saunders A (2005) Applying sustainability assessment models. Impact Assess Project Apprais 23(4):293–302. doi:10.3152/147154605781765436

Regan HM, Colyvan M, Markovchick-Nicholls L (2006) A formal model for consensus and negotiation in environmental management. J Environ Manag 80(2):167–176

Saaty TL (1980) The analytic hierarchy process. McGraw-Hill, New York

Saaty TL (1987) Analytical hierarchy process what it is and how it is used. Math Model 9(3):161–176

Sadler B, Verheem R (1996) SEA: status, challenges and future directions, Report 53. Ministry of Housing, Spatial Planning and the Environment, The Hague

Scace R (2000) Vital relationship: complementary responsibilities of government and proponent in scoping. In: Kennedy A (ed) Cumulative environmental effects management: tools and approaches. Alberta Association of Professional Biologists, Edmonton, pp 31–41

Sheppard SRJ, Meitner M (2005) Using multi-criteria analysis and visualisation for sustainable forest management planning with stakeholder groups. Forest Ecol Manag 207:171–187

Shopley J, Fuggle R (1984) A comprehensive review of current EIA methods and techniques. J Environ Manag 18:25–47

Smit B, Spalding H (1995) Methods for cumulative effects assessment. Environ Impact Assess Rev 15(1):81–106. doi:10.1016/0195-9255(94)00027-X

Sorensen JC (1971) A framework for the identification and control of resource degradation and conflict in multiple use of the coastal zone. Department of Landscape Architecture, University of Carlifornia, Berkeley

Spaling H, Smit B (1993) Cumulative environmental change: conceptual frameworks, evaluation approaches, and institutional perspectives. Environ Manag 17(5):587–600. doi:10.1007/BF02393721

Steinemann A (2001) Improving alternatives for environmental impact assessment. Environ Impact Assess 21:3–21

Sweeney International Management Corp (2009) Environmental Impact Assessment for Kelly Cove Salmon Ltd. proposed aquaculture site relocation for Sand Point, Boston Rock, and Hartz Point. Submitted to NS Department of Fisheries and Aquaculture. SIMCorp. File #SW2008-016, 017 and 018

Therivel R (2004) Strategic environmental assessment in action. Earthscan, Sterling VA

Varma VK, Ferguson I, Wild I (2000) Decision support system for the sustainable forest management. Forest Ecol Manag 128:49–55

Vincke P (1992) Multicriteria decision-aid. Wiley, Chichester

Water Authority of WA (1992) Gnangara Mound vegetation stress study results of investigation, Report No WG 127, Water Authority of WA

Water Authority of WA (1995) Review of proposed changes to environmental conditions -Gnangara Mound groundwater resources (Section 46), Water Authority of WA

Westman WE (1985) Ecology, impact assessment, and environmental planning. Wiley, New York

Wood C, Djeddour M (1991) Strategic environment assessment of policies, plans and programmes. Impact Assess Bull 10(1):3–22

Chapter 15
Project Management Toolbox

Man is a tool-using animal. Without tools he is nothing, with tools he is all

—Thomas Carlyle

15.1 Introduction

When you think of a toolbox, you imagine a collection of handy implements organized well enough, that you can find them when you need them. They're durable and collected over time—some handed down from generation to generation. Most of them are essential, for without them you couldn't imagine starting a tough task. If you add to your collection as the need arises, and if you keep them sharpened, rust-free, and maintained, they'll serve you well for a lifetime (Plummer 2011).

The field of project management uses a customized toolbox, consisting of a significant number of tools to initiate, plan, execute project, and evaluate project performance. This chapter outlines project management tools necessary to carry out the project selection, planning, executing, monitoring and controlling processes using the project management body of knowledge (PMBoK) guide.

The chapter consists of eight sections that focus on the importance of having good project management tools to help eliminate the negative effects of environmental degradation, and use a methodology that is capable of finding solution to the root causes of environmental issues, such as climate change, greenhouse gas emissions, site contamination and municipal wastes.

Section 15.1 is an introduction to project management tools and how they can help projects to be successful. Having good tools is a smart start for managing and running projects effectively and helps the project team and stakeholders to be more successful.

Section 15.2 is about project formulation using project initiation tools. This section consists of four subsections that focus on the early stage of a project. Specific concepts at this stage are selecting the right projects for an organisation that is in alignment with

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the business objectives, fostering creativity and sense of ownership among project team members, obtaining organization/stakeholder support for the project, evaluating the strength, weaknesses, opportunities and threats involved in an environmental project.

Section 15.3 is about developing project scope, using the work breakdown structure (WBS). It consists of five subsections. This section focuses on translating the original project goal into a work unit-oriented structure with initial time and cost estimates. The section outlines the processes for defining project scope and the tools for estimating the defined work. Section 15.4 builds from the content of Sect. 15.3 with tools for implementing the project plan and consists of three subsections: the milestone chart, Pareto chart, and cause-and-effect (Ishikawa) diagram. Sections 15.3 and 15.4 represent the basic processes and core mechanics that every project manager should follow, and generally in the sequence described. Section 15.5 outlines the processes for evaluating project performance using the earned value analysis (EVA), variance analysis and project management software. Sections 15.6 and 15.7 explain how all the tools fit together and their link to project management body of knowledge (PMBoK), while Sect. 15.8 provides the concluding remarks. This chapter seeks the readers to accomplish the following;

1. build effective teams and respond to risk,
2. become familiar with various project management tools,
3. select and customize a project management toolbox by project size or type, and
4. align the project management toolbox with corporate strategy.

These are critical skills in project planning and for building standardized project management processes required for environmental protection, contamination assessment and remediation activities. After reading this chapter, readers will be able to describe various tools to analyse ideas, thoughts and issues in order to make an informed decision.

15.2 Project Initiation Tools

15.2.1 Brainstorming

Brainstorming is a tool used by project teams to bring out the ideas of each individual and present them in an orderly fashion to the rest of the team. The key ingredient is to provide an environment free of criticism for creative and unrestricted exploration of options or solutions. The key advantage of brainstorming is that it helps a team break free of old, ineffective ideas. This free-wheeling technique for generating ideas may produce some that seem half-baked, but it can lead to new and original solutions to problems. Some of the specific benefits of brainstorming include the following:

- It encourages creativity. It expands the thinking of project team members to include all aspects of a problem or a solution. With the help of brainstorming tool, a wide range of options can be identified.
- It rapidly produces a large number of ideas. By encouraging people to offer whatever ideas come to mind, brainstorming tool helps project team members to develop many ideas quickly.
- It equalizes involvement by all team members. Brainstorming provides a non-judgmental environment that encourages everyone to offer ideas. All ideas are recorded.
- It fosters a sense of ownership in decisions. Having all members actively participate in the brainstorming process fosters a sense of ownership in the topic discussed and in the resulting activities. When the people on a team contribute personally to the direction of a decision, they are more likely to support it.
- It provides input to other tools. Brainstorming ideas can be grouped into categories using the affinity diagram or reduce the number of ideas by multi-voting.

Brainstorming is a useful tool for generating a large number of ideas about issues to tackle, possible causes of problems, approaches to use, or actions to take. More information on brainstorming can be found in the book written by Brassard (1988).

15.2.2 Stakeholder Analysis

In project management literature, one of the recent topics mostly discussed is project stakeholder management. It is so important that it was included in the Guide to the project management body of knowledge, 5th edition, (PMBoK Guide) as the 10th knowledge area (see e.g., PMI 2013). A stakeholder is defined as a group or individual that has (or is believed to have) a vested interest in the outcome of a project (PMI 2013). It is very important to perform stakeholder analysis on large projects such as environmental protection/remediation projects, which are expected to cost several million dollars, enhance social advancement, and reduce environmental degradation.

Stakeholder analysis is a process for providing insights into, and understanding of, the interactions between a project and its stakeholders (Grimble and Wellard 1996). It is a powerful tool to help project team members identify and prioritise stakeholders who can have an impact on project success. It can prompt thinking about the type of influence individuals have and in what way they might be an asset (or hindrance) to achieving successful outcomes. It is an essential starting place for understanding critical stakeholders and is the first step for developing engagement strategies for building and maintaining the networks that are necessary for the delivery of successful project outcomes. A major benefit for a team undertaking a stakeholder analysis during the planning and development stages of a project is the opportunity to have an insightful conversation about their project and stakeholders. This may result in the whole team developing a clearer understanding of the range of project stakeholders, thus helping to develop a more focused project strategy.

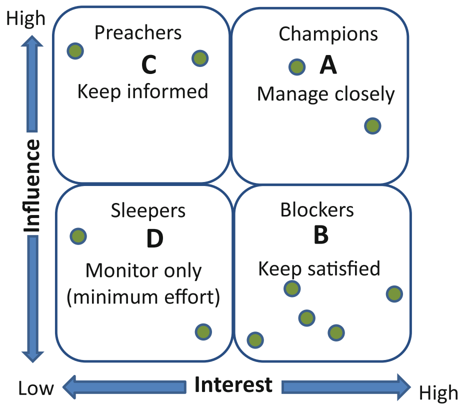

Fig. 15.1 Stakeholder matrix, showing the influence of project stakeholders and their respective interest on project outcome. The *dots* represent number of stakeholders in each box

The power of stakeholders and their interests in the project can be organized in a matrix as shown in Fig. 15.1.

The stakeholder analysis tool consists of five steps, resulting in a stakeholder matrix and a stakeholder analysis table.

Step 1 Identify the stakeholders. This involves identifying the project's stakeholders, and as a team discussing why they are critical for meeting project outcomes.

Step 2 Prioritise the stakeholders. It requires the team to use a matrix (see Fig. 15.1) to prioritise their list of stakeholders in terms of how critical they are in helping deliver on outcomes of the project.

Step 3 Understanding and managing the stakeholders. This involves considering such items as the likely attitudes of the various stakeholders to the project, their attitude to the project team, and any risks associated with their involvement in the project.

Step 4 Setting goals and identifying costs of stakeholder analysis. It requires the team to designate responsibilities for undertaking each communication task and to set appropriate timelines.

Step 5 Evaluation and revision. This step is to be undertaken regularly throughout the life of the project. It is most beneficial when a stakeholder analysis is regularly updated to identify whether there are potential new stakeholders, changes in current stakeholder importance or influence, or if perceptions of the project have changed.

As can be seen in Fig. 15.1, Boxes A, B, C, and D are the key stakeholders of the project. The implications of each box is summarized below:

Box A—The Champions:

These are stakeholders appearing to have a high degree of influence on the project, who are also of high importance for its success. This implies that the implementing organisation will need to construct good working relationships with these stakeholders, to ensure an effective coalition of support for the project. They can make big impact on the success of the project as well, and can use their influence to get rid of barriers and obstacles for the project. Examples might be the senior officials and department of environment and conservation (DEC) or trade unions.

Box B—The Blockers:

These are stakeholders of high importance to the success of the project, but with low influence. This implies that they will require special initiatives if their interests are to be protected. Watch for these set of stakeholders as their high energy makes them likely to communicate widely, influence effectively, and act vigorously. Their low commitment to your change affects what they say and do, which makes them likely to land up standing in your way. An example may be traditionally marginalised groups (e.g., Indigenous people, youth, seniors), who might be beneficiaries of a new service, but who have little ‘voice’ in its development.

Box C—The Preachers:

These are stakeholders with high influence, who can therefore affect the project outcomes, but whose interests are not necessarily aligned with the overall goals of the project. They might be financial administrators, who can exercise considerable discretion over funding disbursements. This conclusion implies that these stakeholders may be a source of significant risk, and they will need careful monitoring and management.

Box D—The Sleepers:

Well, the hint is in the name. The stakeholders in this box have neither interest in, nor influence on the project. They are not really committed to your change and don’t have the energy to do anything about it or talk about it. Unless you know who they are because they don’t understand what is coming, (and therefore might move to another quadrant when they find out) you don’t need to exert too much time or effort looking after them. They require limited monitoring or evaluation, but are of low priority.

The key to using this matrix is not just doing the analysis, but actually doing something active with the results. For example, when you find “blockers”, it may be their low commitment is based on misunderstandings or fear and uncertainty. In many cases, it’s possible to engage these people and turn them into “champions”. If not, it is important to find ways to counteract the communications and actions of these people (particularly if they have positions of power and/or influence).

15.2.3 SWOT Analysis

SWOT analysis is a structured planning tool which can be used to evaluate the strengths, weaknesses, opportunities and threats (SWOT) involved in an environmental project. Lozano and Valles (2007) state that “SWOT analysis is widely recognised and it constitutes an important basis for learning about the situation and for designing future procedures, which can be seen necessary for thinking in a strategic way”.

However, the use of this method gives rise to some important advantages and disadvantages. The advantages, for instance, may include the idea that this method is very simple and everybody can use it without having advanced knowledge or external technical support. The disadvantages refer to a variety of shortcomings regarding this tool such as its simplistic, static and subjective character. These shortcomings have influenced the transparency of the results of SWOT analysis.

The tool is credited to Albert Humphrey (2005), who led a convention at the Stanford Research Institute in the 1960 and 1970s using data from Fortune 500 companies. The degree to which the internal environment of the firm matches with the external environment is expressed by the concept of strategic fit.

Specifically, SWOT is a basic, straightforward model that assesses what an organization can and cannot do as well as its potential opportunities and threats. The method of SWOT analysis is to take the information from an environmental project analysis and separate it into internal (strengths and weaknesses/limitations) and external issues (opportunities and threats). Once this is completed, SWOT analysis determines what may assist the firm in accomplishing its objectives, and what obstacles must be overcome or minimized to achieve desired results.

Figure 15.2 shows various factors to be considered when implementing the objectives of SWOT analysis for environmental project planning.

Preparation of a SWOT analysis involves the following procedure:

1. Establish objectives: Setting the objective should be done after the SWOT analysis has been performed. This would allow achievable goals or objectives to be set for the project.

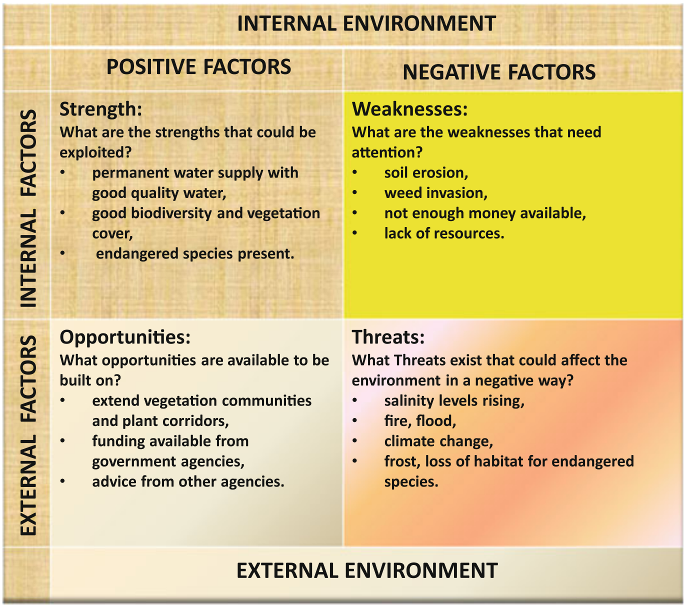

Fig. 15.2 SWOT matrix used for performing environmental project analysis

2. Develop SWOT analysis:
   - **Strengths** identify the characteristics of the project that give it an advantage over others;
   - **Weaknesses** are characteristics that place the project team at a disadvantage relative to others;
   - **Opportunities** are elements that the project could exploit to its advantage;
   - **Threats** are elements in the external environment that could cause trouble for the project, and hinder it from being successful.
3. List SWOT factors:
   - List all the internal factors (strength and weaknesses) of the project;
   - List all the external factors (opportunities and threats) facing the project.

Identification of SWOTs is important because they can inform later steps in planning to achieve the objective. First, the decision makers should consider whether the objective is attainable, given the strengths, weakness, opportunities and threats. If the objective is not attainable a different objective must be selected and the process repeated. Users of SWOT analysis need to ask and answer questions that generate meaningful information for each SWOT factor to make the analysis useful and find their competitive advantage.

15.2.4 Project Portfolio Selection and Optimization

Firms are literally bombarded with opportunities, but no organisation enjoys infinite resources with which to pursue every opportunity that presents itself. Choices must be made, and to best ensure that they select the most viable projects, portfolio optimization models (e.g., linear programming, integer programming, quadratic programming, stochastic programming, dynamic programming, nonlinear programming, etc.) are used for balancing the opportunities and risks entailed by each alternative (see e.g., Sholarin 1989; Campbell 2001; Pinto 2013). From project management perspective, a portfolio is defined as "a set of projects and/or programs and other work that are grouped together to facilitate the effective management of the work to meet company's strategic business objectives" (PMI 2006a, b).

The basic concepts behind portfolio optimization are widely recognized and understood (see e.g., Hightower and David 1991; Edwards and Hewett 1993; Orman and Duggan 1998; Campbell 2001). Originally, portfolio optimization was a securities-investment-optimization tool. It assumes that given the expected return and risk of a security, along with its correlation with other securities in a portfolio, a selection of stocks can be chosen that maximizes the return for any level of risk. The mechanics of portfolio theory is based on the underlying assumptions that investors are *risk averse*, that is, given two or more projects with the same expected return, investors will prefer the less risky one. Thus, an investor will take on increased risk only if compensated by higher expected returns. Conversely, an investor who wants higher returns must accept more risk. The exact trade-off will differ from one investor to another based on individual risk aversion characteristics.

Because projects are combination of "unique" discrete entities, an optimal portfolio is a feasible set of points that form the *efficient frontier* rather than a continuous line as originally developed by the theory. Thus, according to Markowitz (1959) efficient frontier is the set of all portfolios that will give the highest expected return for each given level of risk (see Fig. 15.3). The horizontal axis represents risk (typically in the form of standard deviation of return in dollars), while the vertical axis represents return (typically in the form of the expected mean return of the portfolio). The line, which depicts the efficient frontier itself, represents the highest level of expected return for any given level of risk with any possible combination of projects within the portfolio. The area under the curve is populated by every other "non-efficient" portfolio that can exist. A value can be increased by moving from (μ_1) to (μ_2), or risk can be decreased by moving from σ_1 to σ_2. Therefore, the efficient frontier is the curve of optimal risk-return trade-offs, from which a decision-maker can select the one which best suits his/her tolerance for risk. Plotting an investment portfolio as shown in Fig. 15.3 is an extremely useful approach to understanding risk and return.

For illustration, a set of five investment opportunities, a mix of environmental protection, remediation and waste reduction projects, was evaluated under various scenarios to develop a robust understanding of a typical project portfolio with the respective NPV and present-worth-ratio (PWR) indicators. Table 15.1 illustrates how to rank and choose environmental projects to invest in, by means of PWR at an 8 % discount rate, if limited funds were available (see e.g., Sholarin 2007).

At the portfolio level, a $300 million budget was imposed, enabling one-to-one comparison of the computer-optimized portfolio solution to the PWR portfolio. On a standalone basis, Project ENV5 had the highest PWR. Under traditional decision-making guidelines, for a risk-averse investor, Project ENV5 would be preferred over other environmental projects. Although Project ENV1 had the highest NPV, its PWR is less than that of Projects ENV3 and ENV5. However, when viewed from the portfolio framework, the results were different.

Table 15.2 shows the portfolio mean and standard deviation (SD) of NPV for five possible project portfolio investments. Portfolio A represents an optimized oppor-

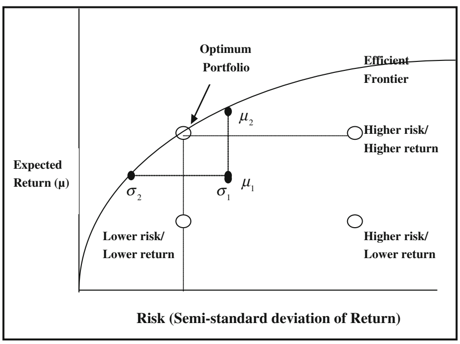

Fig. 15.3 Example of an efficient frontier, showing an optimal portfolio as a feasible set of points from (μ_1) to (μ_2); or from (σ_1) to (σ_2)

Table 15.1 Selecting environmental projects with the highest NPV using PWR

Environmental	Capital	NPV @ 10 %	Ranking by NPV	PWR @ 10 %	Ranking by PWR
Project ID	$ Million	$ Million			
ENV 1	100	42	1st	0.42	3rd
ENV 2	200	40	2nd	0.2	4th
ENV 3	75	35	3rd	0.47	2nd
ENV 4	150	20	5th	0.13	5th
ENV 5	50	30	4th	0.6	1st
BUDGET	300		**82**		**122**

Table 15.2 Portfolio combinations of environmental projects, using standard deviation as the expected mean return in dollars

Environmental	Portfolio	Total cost	Total NPV	Mean NPV	SD
Project portfolio	Set	$ Million	$ Million	$ Million	$ Million
A	ENV 1, 3, 5	225	107	110.8	22.65
B	ENV 1, 2	300	82	80.4	32.75
C	ENV 2, 3	275	75	76.1	30
D	ENV 3, 4, 5	275	85	83.8	27.25
E	ENV 1, 4, 5	300	92	90.8	28.45

tunity set generated by selecting environmental projects according to their PWR ranking. This opportunity mix include three projects and has little or no risk compared to other portfolios with similar returns. Compared to portfolio A, portfolio D is an opportunity mix of environmental portfolio set, comprising of projects ENV3, ENV4, and ENV5. This solution has 20 % more risk than portfolio A based on PWR ranking. Portfolio B, C, and E have high values for NPV, but also have high-risk levels compared with portfolio A (see Table 15.2).

As rightly noted by Edwards and Hewett (1993), the goal of portfolio theory is not to determine at exactly which risk level to operate, or which specific efficient portfolio to select. Rather, the goal is to eliminate inefficient portfolios for which, for any given level of risk, there is another available portfolio, which has a greater return.

15.3 Project Planning Tools

15.3.1 Affinity Diagram

An Affinity diagram is a tool that gathers large amount of language data (ideas, opinions, issues) and organises them into groupings based on their natural relationships. An Affinity diagram is used to organize and categorise ideas or issues generated by team members during brainstorming sessions. The process is a good way to get project team to work on a creative level to address difficult issues. It may be used in situations that are unknown or unexplored by a team, or in circumstances that seem confusing or disorganised, such as when project team with diverse experiences form a new team, or when members have incomplete knowledge of the area of analysis.

An affinity exercise is an excellent way to get a group of people to react on a "gut level" rather than mulling things over intellectually. Since brainstorming is the first step in making an Affinity Diagram, the team considers all ideas from all members without criticism. This stimulus is often enough to break through traditional or entrenched thinking, enabling the team to develop a creative list of ideas. An Affinity diagram is useful when you want to sift through large volumes of data. For example, an environmental manager who is identifying various environmental remediation technologies and their associated costs might compile a very large list of unsorted data. In such a case, creating an Affinity diagram might be helpful for organising the data into groups.

Affinitizing is a process performed by a group or team. The idea is to meld the perspectives, opinions, and insights of a group of people who are knowledgeable about the issues. The process of developing an Affinity Diagram seems to work best when there are no more than five or six participants.

In preparing for an Affinity diagram, here are a few recommendations:

- Affinitize silently: The most effective way to work is to have everyone move the displayed ideas at will, without talking. This is a new experience for many people. It has two positive results: it encourages unconventional thinking (which is good), while it discourages semantic battles (which are bad). It also helps prevent one person from steering the affinity.
- Go for gut reactions: Encourage team members not to agonize over sorting but to react quickly to what they see. Speed rather than deliberation is the order of the day, so keep the process moving.
- Handle disagreements simply. The process provides a simple way to handle disagreements over the placement of ideas; if a team member doesn't like where an idea is grouped, he or she moves it. This creates an environment in which it is okay to disagree with people having a different viewpoint. If consensus cannot be reached, make a duplicate of the idea and place one copy in each group.

Now let's walk through the step-by-step process of creating an Affinity diagram as suggested by Brassard (1989):

Step 1 Affinity diagram problem statement: Write a problem or an issue statement.

Step 2 Affinity diagram brainstorming session: Generate a list of ideas for solving the problem or tapping the opportunity, using the brainstorming tool. The ideas are then displayed on the affinity diagram. The ideas need to be short, clear, precise sentences. The rest of the steps in the Affinity process will be easier, if these ideas are written on post-it notes. An example of a typical idea generation technique using affinity diagram is shown in Fig. 15.4.

Step 3 Sort ideas or issues into related groups: Move the post-it-notes into groups. This exercise is to find the logical connections of thoughts. After the groups

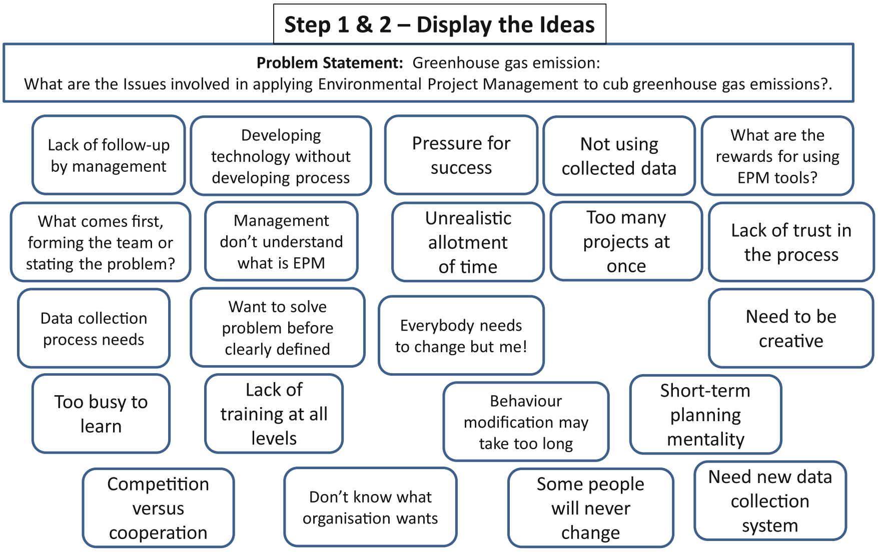

Fig. 15.4 Display of ideas using affinity diagram: The ideas generated by project team members are alligned with the problem statement

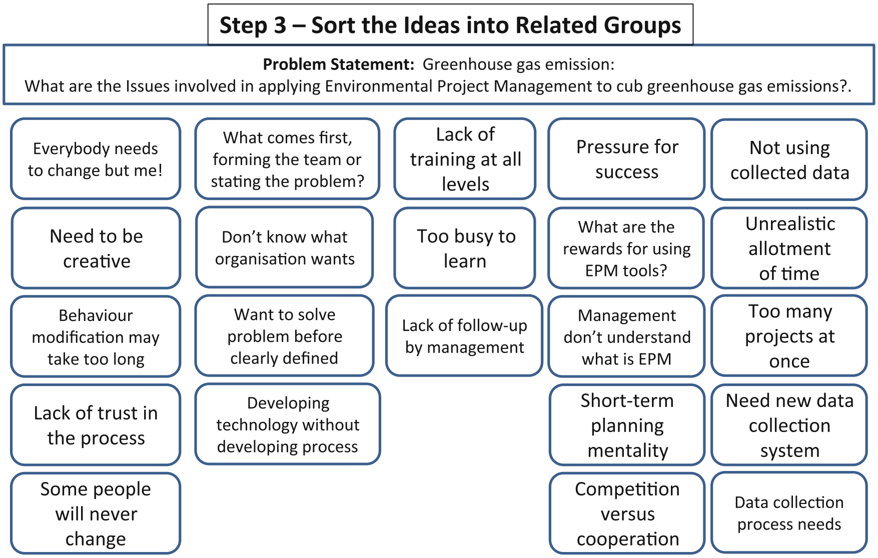

Fig. 15.5 Sort ideas into related groups using affinity diagram

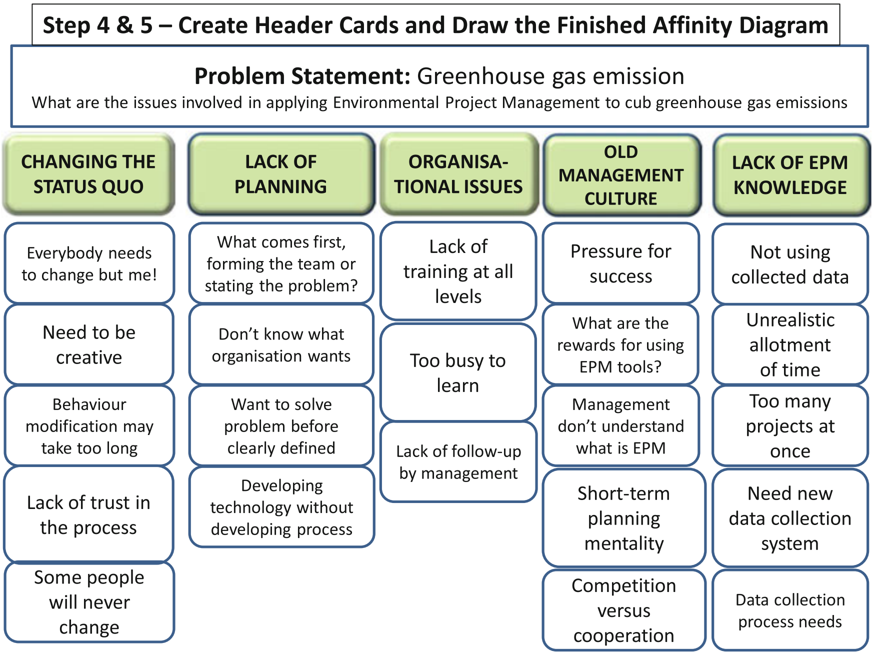

Fig. 15.6 Finished affinity diagram with super header cards shown in *green colour*: The ideas are grouped together under different categories in preparation for developing a WBS discussed in Sect. 15.3.2

are sorted as shown in Fig. 15.5, create summary or header cards for each group.

Step 4 Create header cards for the groups. A header is an idea that captures the essential link among the ideas contained in a group of cards. The idea is written on a single post-it note and must consist of a phrase or sentence that clearly conveys the meaning, even to people who are not on the team.

Step 5 Draw the finished Affinity diagram.

The super header cards (post-it notes) should indicate the central idea of a group and its contents. The Affinity diagram is the finalised header card with their groupings as seen in Fig. 15.6.

15.3.2 The Work Breakdown Structure (WBS)

A work breakdown structure (WBS) is a logically structured hierarchical decomposition of the work to be executed by the project team in order to accomplish the project objectives (Haugan 2002; PMI 2006a, b). Because most projects involve many people and many deliverables, it is important to organize and divide the work into logical parts based on how the work will be performed. The WBS is the "skeleton" of the

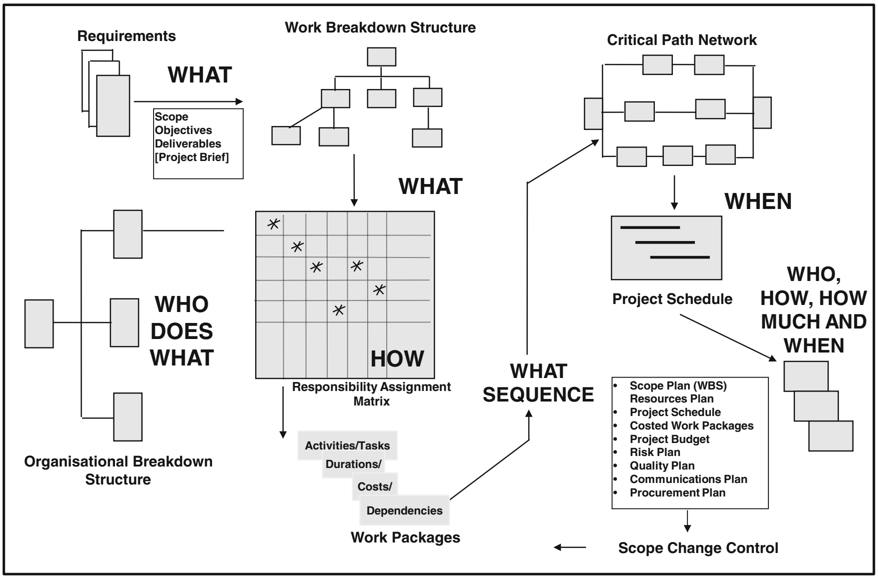

Fig. 15.7 Central role of the WBS in project scope planning, scheduling and control: WBS is used for developing the responsibility assignment matrix (RAM), network diagram, Gantt chart and project performance baseline

project management body of knowledge (PMBoK) because it provides the basis for planning, organising and managing project schedules, costs, resources, and potential changes. The use of WBS helps to assure project managers that all products and work elements are identified, to integrate the project with the organisational structure and to establish a basis for control. The WBS also makes it possible to plan, schedule, and budget. It gives framework for tracking cost and work performance at different stages of project life cycle. Thus, WBS is the most important project planning tool because it completely identifies all the work that is described by the project scope and provides the basis for detailed project planning, integration, communication, implementation and control. The central role of the WBS in project scope planning, integration and control is illustrated in Fig. 15.7.

The WBS is the single most important element because it provides a common framework from which;

- total program or project can be described as a summation of a subdivided elements,
- planning can be performed,
- costs and budgets can be established,
- time, cost, performance and risk can be tracked,
- objectives can be linked to company resources in a logical manner,
- schedules and status reporting procedures can be established,
- network construction and control planning can be initiated, and
- responsibility assignment matrix for each element can be established.

15.3.3 *Responsibility Assignment Matrix (RAM)*

In many cases, the size and scope of the project do not warrant an elaborate work breakdown structure (WBS) or organisational breakdown structure (OBS). One tool that is widely used for this purpose is the responsibility assignment matrix (RAM). Some authors (see, e.g., Havranek 1999) call it *linear responsibility chart* (LRC), while others call it *matrix responsibility chart* (MRC) or *responsibility interface matrix* (RIM), (see e.g., Vaidyanathan 2013; Shtub et al. 2005). The WBS and OBS can be combined to produce a responsibility assignment matrix (RAM), which links the work to be done with the assigned organization, department or person. The PMBoK Guide defines the responsibility assignment matrix as a "grid that shows the project resources assigned to each work package. It is used to illustrate the connections between work packages or activities and project team members" (PMI 2013). The RAM summarises the tasks to be accomplished and who is responsible for what on a project in its simplest form. A RAM consists of a chart listing all the project activities and the participants responsible for each activity. An example of a RAM is shown in Fig. 15.8.

The figure illustrates a RAM for carbon capture and sequestration project. In this matrix, P is used to identify the committee member who has the primary responsibility for coordinating the efforts of other team members assigned to the task and making

WBS ID	Work Description	Ben	Rob	Jim	Jack	Doug	Steve	Joe	Hannah
0.0	**Carbon Capture and Storage Project**								
1.0	**Carbon dioxide capture**		P	S		P			
1.1	Initial investigation		S	P			P		P
1.2	Extended investigation	S				S		P	
1.3	Environmental risk assessment		S	P	S				
1.3.1	Estimate C02 intake			S	P			P	
1.3.2	Toxicity/Wetability assessment				S				P
1.4	HSE construction and operations	P	S		P				
2.0	**Carbon dioxide transportation**					P	S		
2.1	Feasibility studies	S	P		P				
2.1.1	Development of alternatives				S			P	S
2.1.2	Screening of alternatives		S				S	P	
2.1.2.1	Further define alternatives				S			P	S
2.1.2.2	Verify specific actions							P	
2.1.3	Detailed analyis of alternatives			P		S	S	P	
2.1.3.1	Compare against each other	P	S		P				
2.1.3.2	Criterion analysis			S		P			P
2.2	Pilot testing		P		S				S
2.3	Operation and maintenance	S							
3.0	**Carbon dioxide storage**		S	P		S	P		
3.1	Project engineering			S				P	
3.2	Treatability studies	S			P			S	
4.0	**Project management**			P					S
4.1	Scope planning and control		S			P	P		
4.2	Schedule planning and control		P		S				
4.3	Cost planning and control	S		P					
4.4	Resource planning and control	S	S						P
KEY:	**Accountable team member: P = Primary responsibility; S: Support responsibility**								

Fig. 15.8 Responsibility assignment matrix for carbon capture and storage (CCS) project, showing who is primarily responsible (P) and who is having only supporting role (S)

sure the task is completed. The S is used to identify members of the eight person team who will support and/or assist the individual responsible.

Simple RAM like the one shown in Fig. 15.8 are useful not only for organising and assigning responsibilities for small projects but also for subprojects of large, more complex projects. By plotting tasks against a team member on a matrix and labelling each person's assignments as responsible or accountable, it provides a quick and easy view of who is responsible for each project component and who is accountable, i.e., supporting an individual responsible for the deliverable. More complex RAMs not only identify individual responsibilities but also clarify critical interfaces between units and individuals that require coordination.

15.3.4 Network Diagram

A network diagram may be defined as the graphical representation of project activities showing the planned sequence of work. It is a tool used to plan the appropriate sequence or schedule for a set of tasks and related subtasks of a project. The diagram enables one to determine the *critical path* (longest sequence of tasks). Figure 15.9 shows the network diagram for the example shown in Table 15.3. The network diagram shown in Fig. 15.9, using the arrow diagramming method (ADM) discussed in Sect. 16.5.1.1, illustrates all the intended dependencies of the project. Durations is shown in weeks. The activities are connected to their predecessors by an arrow, and all the activities need to be completed in order to finish the project. Figure 15.9 shows the network diagram, which can be represented in the Microsoft Project software package.

Constructing a network diagram is an exercise in patience and discipline that involves proceeding through several major steps. In it, as with all project planning or schedule development tools, a crucial step is to determine the level of detail and to identify activities. The process of building a network diagram tool, using a critical path method (CPM), discussed in Sect. 16.5.1, is destined to produce a better product if quality information about the following inputs is developed;

- project scope,
- responsibility assignment matrix (RAM),

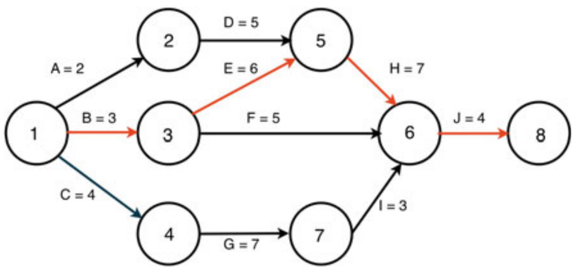

Fig. 15.9 Activity-on-Arrow (AOA) network diagram constructed using the information derived from Table 15.3. The *red lines* signify the critical path, while the *black lines* signify non-critical path. More about AOA method is discussed in Sect. 16.5.1.1

Table 15.3 Sequence of activities and events in an environmental project

Activity	Description	Activity predecessor	Duration (Weeks)
A	Scoping	–	2
B	Screening	–	3
C	Environmental impact assessment	–	4
D	Project planning	A	5
E	Decision tree analysis	B	6
F	Project implementation	B	5
G	Project status report	C	7
H	Environmental review	D, E	7
I	Project close out	G	3
J	Lesson learned	F, H, I	4

- resource allocation, and
- schedule management system.

In this context, the purpose of the information about the scope is to provide schedulers with the knowledge of the project activities that are being scheduled. Clear definition of responsibilities—who does what in the project—points to who has the best information about the individual activities and should therefore schedule them.

To develop realistic schedules, these "owners" of the activities also need to know which resources are available and when. Finally, the schedule management system will direct schedulers in developing a network diagram, using critical path method (CPM) discussed in Sect. 16.5.1.

15.3.5 Gantt Chart

One of the first modern tools used to assist in project planning is a version of the bar chart developed in 1917 by Henry Laurence Gantt (1861–1919), an American mechanical engineer. It is considered one of the earliest and most recognised project planning tools in project management (Taylor 2008).

The first Gantt chart was developed for planning the building ships during the World War One. A Gantt chart is prepared by listing the work activities as discrete tasks on a horizontal axis and plotting each one against a timeline on the vertical axis. The task duration is shown as a rectangle on the timescale. In this way, the chart (linked and/or unlinked Gantt task bars) can quickly convey the overall plan, the completed work to date and the individual status of the total project (see Fig. 15.10b).

The duration of each activity in the network shown in Fig. 15.10a can be represented on a time scale (Fig. 15.10b). This representation is known as a bar or Gantt

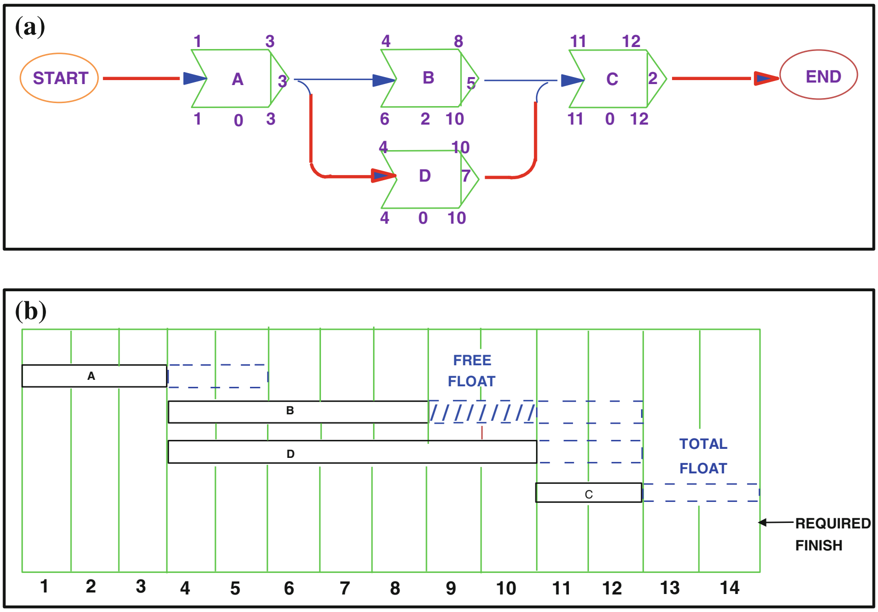

Fig. 15.10 Network diagram versus Gantt chart: The A, B, C, and D represents the project task, while the numbers on the horizontal bar represent the period of time

chart. A Gantt chart can be created using project management software, such as MS Project or Primavera.

Having a Gantt chart helps ensure that everyone understands the timetable for project activities. Then, project participants will have the necessary time allocated on their calendars and be available to perform their activities.

The chart has the advantages in that it is:

- Visual: It shows graphically which activities are ahead of or behind schedule. This makes it a superb communication tool.
- Simple: With little or no instruction, almost everyone can read or construct a Gantt chart, from a project team member to the executive sponsor.
- Useful in resource scheduling or allocation: First marking on each activity the numbers of different human resources and adding them up for each time period helps get the total number of a certain resource over time for each activity and the whole project.
- being commonly used and easily understood.

However, Gantt charts have disadvantages that may limit its relevance. In particular, they:

- do not show dependencies between activities, making it impossible to clearly identify the sequence of the project activities and, consequently, the critical path. With-

out this information, Gantt charts are not effective in large and cross-functional projects;
- do not clearly show the linkages between various tasks nor the relationships between resources and time to complete the task;
- being difficult to use for project tracking without computer support;
- are unable to provide information about how to get a project back on track;
- cannot cope effectively with projects containing large number of activities, measured in hundreds, for example. This can be overcome by using hierarchical Gantt charts, in which an activity in a higher-level Gantt chart is broken down into more detailed activities in the lower-level Gantt chart;

15.4 Project Implementation Tools

15.4.1 Milestone Chart

A milestone chart shows milestones against the timescale in order to signify the key events and to draw management attention to them (see Fig. 15.11). Milestone is defined as a point in time or event whose importance lies in it being the climax point for many converging dependencies. Hence, "Basis for design" is a distinctive milestone for the completion of prefeasibility studies in an oil field development project, and "final investment decision (FID)" is a characteristic milestone for well engineering projects.

While these milestones relate to the completion of key deliverables, other types may include the start and finish of major project phases, stage gates, events external

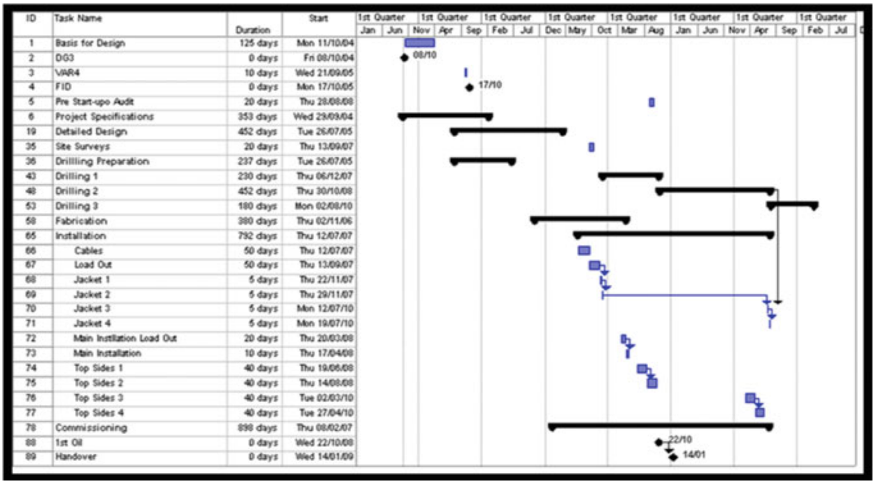

Fig. 15.11 An example of a milestone chart

to the project (e.g., project initiation review, feasibility review, concept selection and development review), and so forth.

15.4.2 Pareto Chart

Pareto chart, also referred to as *Pareto diagram*, is a specific type of histogram, ordered by frequency of occurrence. It shows how many defects were generated by type or category of identified causes (see Fig. 15.12). Rank ordering is used to focus corrective action. Pareto chart is conceptually related to Pareto's law, often called the 80/20 principle, which holds that a relatively small number of causes will typically produce a majority of the problems or defects, that is, 80 % of the problems are due to 20 % of the causes. It is a very useful tool for separating the vital few from the trivial many. Pareto chart can also be used to summarise various types of data for 80/20 analysis.

Pareto chart is a simple bar graph where the y-axis represents frequency of occurrence and x-axis represents the reasons. The bars are arranged in descending order of height from left to right. The bars on the left are relatively more important than those on the right. This means the categories represented by the tall bars on the left are relatively more significant than those on the right (Scholtes et al. 1988).

The benefits of using Pareto chart can be thought of in economic terms. A Pareto chart breaks a big problem into smaller pieces and identifies the biggest contributors in such a way as to get the most improvement with the resources available by showing where to focus efforts in order to maximize achievements. The Pareto principle states that a small number of causes accounts for most of the problems. Focusing efforts on the vital few causes is usually a better use of valuable resources.

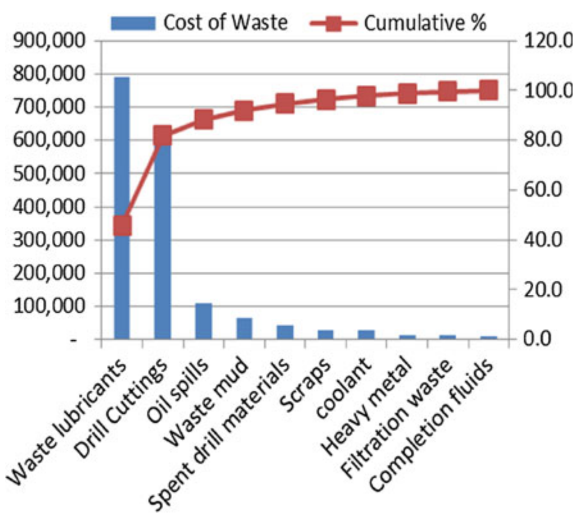

Fig. 15.12 Pareto chart analysis for industrial wastes: The vertical axis shows cost of wastes in dollars (represented by the *blue bars*), while *red line* shows the cumulative percent of wastes

Pareto Chart Procedure

To construct a Pareto chart, a meaningful data have to be collected and categorised. Then the following steps have to be taken:

Step 1 Record the raw data. List each category and its associated data count.
Step 2 Order the data. Prepare an analysis sheet, putting the categories in order and placing the one with the largest count first.
Step 3 Label the left-hand vertical axis. Make sure the labels are spaced in equal intervals from 0 to a round number equal to or just larger than the total of all counts. Provide a caption to describe the unit of measurement being used.
Step 4 Label the horizontal axis. Make the widths of all of the bars the same and label the categories from largest to smallest.
Step 5 Plot a bar for each category. The height of each bar should equal the count for that category. The width of the bars should be identical.
Step 6 Find the cumulative counts. Each category's cumulative count is the count for that category added to the counts for all larger categories.
Step 7 Add a cumulative line. This is optional. Label the right axis from 0 to 100 % and line up the 100 % with the grand total on the left axis. For each category, put a dot as high as the cumulative total and in line with the right edge of that categories bar. Connect all the dots with straight lines.
Step 8 Add title, legend, and date.
Step 9 Analyse the diagram. Look for the break point on the cumulative percent graph. It can be identified by a marked change in the slope of the graph (see Fig. 15.12). This separates the significant few from the trivial many.

Often a bar chart is generated, descending from left to right, with larger economic losses on the left side of the Chart.

Example of a Pareto Chart

Now let's look at an example to illustrate the Pareto chart construction process. Suppose you are an environmental project manager for your company, the management has just approved $1,722,000 and would like to apply it to some of waste reduction initiatives. The costs of various type of waste is shown in Table 15.4.

The Pareto chart shown in Fig. 15.12 depicts a bar chart with each waste on the horizontal axis and associated costs on the vertical axis. This is a good example of the 80/20 rule. Waste lubricants and drilling cuttings contributes most to the waste stream for rig operations. They cost $1,410,000 of a total waste cost of $1,722,000. That's close to 82 % of the cost for two out of the ten waste types addressed.

To reduce waste and save money, efforts needs to focus on testing oil lubricants to extend its use based on wear versus accumulated operating hours. The lubricants should be recycled whenever possible. Specific drilling cutting should also be used for a specific drilling operation in order to minimize drilling hole size. Besides, drilling mud activities should be designed and monitored to minimize caving. Moreover, organic additives, polymers, and biodegradable additives can be substituted for oil-based mud to reduce costs associated with cleanup of oil-based drill cuttings.

Table 15.4 Most common type of wastes in rig operations

Most Common type of waste in rig operations				
	Type of waste	Cost of waste	Cumulative	Cumulative %
1	Waste lubricants	789,000	789,000	45.8
2	Drill cuttings	621,000	1,410,000	81.9
3	Oil spills	109,000	1,519,000	88.2
4	Waste mud	65,000	1,584,000	92.0
5	Spent drill materials	45,000	1,629,000	94.6
6	Scraps	30,000	1,659,000	96.3
7	Coolant	27,000	1,686,000	97.9
8	Heavy metal	15,000	1,701,000	98.8
9	Filtration waste	12,000	1,713,000	99.5
10	Completion fluids	9,000	1,722,000	100.0
	Total	1,722,000		

In summary, there are positive side effects to focusing on a problem. Addressing the important effects often leads to addressing the lesser important ones as well.

15.4.3 Cause-and-Effect (Ishikawa) Diagram

Ishikawa or cause-and-effect (C&E) diagram is the brainchild of Kaoru Ishikawa, who pioneered quality management processes in the Kawasaki shipyards and in the process, became one of the founding fathers of modern management. That's why the diagram is named after him as Ishikawa diagram or Ishikawa analysis. Ishikawa diagram is also known as the *fishbone diagram* because it was drawn to resemble the skeleton of a fish, with the main causal categories drawn as "bones" attached to the spine of the fish as shown in Fig. 15.13.

Ishikawa diagram is a tool that helps identify, sort, and display possible causes of a specific problem or effect. It graphically illustrates the relationship between a given outcome and all the factors that influence the outcome. It also illustrates how various factors might link to potential problems or effects. A possible root cause can be uncovered by continuing to ask "why" or "how" along one of the lines (PMI 2013).

Causes in the diagram are usually grouped into six major categories to identify these sources of variation. The categories typically include:

1. **People**: Anyone involved with the process.
2. **Methods**: How the process is performed and the specific requirements for doing it, such as policies, procedures, rules, regulations and laws.
3. **Technology**: Any equipment, computers, tools, etc., required to accomplish the job.
4. **Materials**: Raw materials, parts, pens, paper, etc. used to produce the final product, or cause an environmental effect (e.g., scrap metals, landuse, radiation, etc.)

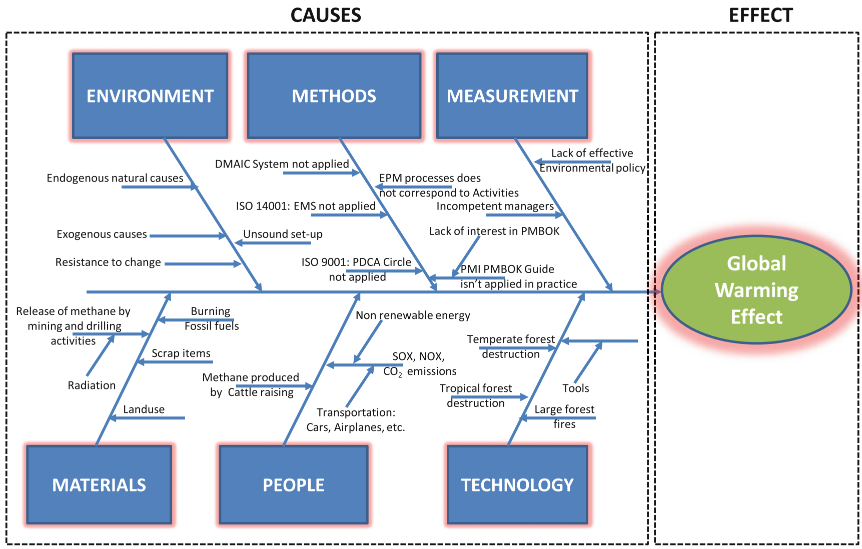

Fig. 15.13 Ishikawa diagram showing causes and global warming effect of energy production

5. **Measurements**: Data generated from the process that are used to evaluate its quality.
6. **Environment**: The conditions, such as location, time, temperature, and culture in which the process operates.

The most common categories are the first four. Constructing a Ishikawa diagram can help project team identify the possible root causes, the basic reasons, for a specific effect, problem, or condition. It also helps to sort out and relate some of the interactions among the factors affecting a particular process or effect. Moreover, Ishikawa diagram can be used to analyse existing problems so that corrective action can be taken.

Some of the benefits of constructing a Ishikawa diagram include the following;

- helps determine the root causes of a problem or quality characteristic using a structured approach,
- encourages group participation and utilizes group knowledge of the process,
- uses an orderly, easy-to-read format to diagram cause-and-effect relationships,
- used to break down complex multifaceted problems into element issues,
- increases knowledge of the process by helping everyone to learn more about the factors at work and how they relate, and
- identifies areas where data should be collected for further study.

The weaknesses of an Ishikawa diagram include the following;

- team must have understanding of the problem,
- some team members have difficulty with categorizing and sub-categorizing issues,
- result is a list of problem elements, not solutions.

Ishikawa Diagram Procedure

To develop an Ishikawa diagram, a structured pictorial display of a list of causes is constructed and organised to show their causal relationship to a specific effect (see Fig. 15.13). Notice that the diagram has a cause side and an effect side.

The steps for constructing and analysing a fishbone diagram are outlined below:

Step 1 Identify and clearly define the outcome or effect to be analysed. This can be done in form of problem statement. Decide on the effect to be examined. Effects are stated as particular quality characteristics, problems resulting from work, planning objectives, and the like.

Step 2 Draw a horizontal arrow pointing to the right. This is the spine. To the right of the arrow, write a brief description of the effect or outcome which results from the process. For example, the effect might be global warming, oil spill, industrial wastes, greenhouse gas emissions.

Step 3 Establish the main causes, or categories, under which other possible causes will be listed. Write the main categories your team has selected to the left of the effect box, some above the spine and some below it. Finally, draw a box around each category label and use a diagonal line to form a branch connecting the box to the spine.

Example of Ishikawa Diagram

For illustration, let us consider root causes of greenhouse gas emissions as a result of energy production using the Ishikawa diagram.

Energy is an essential basic need not only for human beings, but also for national economic and social development. However, production of energy is found to exhibit both local and global environmental impacts, if appropriate technology and management are not implemented (see, e.g., Othieno and Awange 2015). In other word, to produce energy from fuel combustion, the carbon major content of fuels would react with O_2 to obtain CO_2 emission, and the minor contents of sulfur (S) and nitrogen (N) would react with O_2 to obtain SO_x and NO_x emissions, and also emissions of CO and particulate due to unburned materials. The CO_2 emission is well known to cause greenhouse gas effect and global warming, which is global concerns and needs international cooperation to address with; while the SO_x and NO_x emissions are well-known to cause acid rain (see Fig. 15.13).

15.5 Project Performance Evaluation Tools

The purpose of this section is first to describe project control theory in general, and then to explain and discuss earned value analysis as a performance evaluation tool that is now used by a number of organisations across the world. The section on earned value covers all aspects of the approach, from definition to application in a variety of situations.

When the planning phase is over (and agreed), the "doing" phase begins. Once it is in motion, a project acquires a direction and momentum, which is totally independent of anything that was originally predicted. In order to increase the likelihood of achieving successful outcome in a project, it is crucial to establish at the beginning (within the project plan), the means of monitoring and influencing the project's progress.

To monitor progress, to receive early signal of danger, to promote cooperation, to motivate through team involvement, all of these rely upon communication. Regular reports are invaluable for effective monitoring and control. Merely saying: "project is progressing according to schedule" is not enough. A project report must include concrete and tangible figures and measurements, showing whether a project is progressing according to schedule or not. If not, then something has to be done about it.

Project performance evaluation involves using the time-phased dollar schedule from Gantt chart such as the one shown in Fig. 15.14, the WBS/OBS matrix shown in Fig. 16.4 and network diagram of work packages as shown in Fig. 15.10 to develop a baseline chart.

Using the example in Fig. 15.14, the baseline chart is expressed as the running total to give the characteristic 'S-curve' as shown in Fig. 15.15.

The S-curve is then used to show the trend in, and the difference between the budget, actual and predicted spend. Ultimately, the curve forms the basis of a project schedule, cost and performance tracking technique, using the performance evaluation tool known as *earned value analysis (EVA)*, which will be discussed in the next section. The curve looks like an 'S' with the bottom tail of the curve at time zero and the top tail corresponding to project completion (see e.g., Wideman 1991). By plotting the cumulative resources required against time, the planned progress of the project can be illustrated.

Schedule information						Baseline budget needs											
						Time period											
WBS ID	Duration	ES	LS	TF	CTR Estimate ($'000)	1	2	3	4	5	6	7	8	9	10	11	12
A	1	1	1	0	2	2											
B	3	2	2	0	18		6	6	6								
C	2	2	3	1	4						2	2					
D	5	5	5	0	15					3	3	3	3	3			
E	2	4	8	4	2								1	1			
F	3	10	10	0	6										2	2	2
TOTAL BCWS (PV) by period						**2**	**6**	**6**	**6**	**3**	**5**	**5**	**4**	**4**	**2**	**2**	**2**
Cumulative BCWS (PV) by period						**2**	**8**	**14**	**20**	**23**	**28**	**33**	**37**	**41**	**43**	**45**	**47**

Fig. 15.14 The baseline chart, showing budget requirements of project activities over a period of time

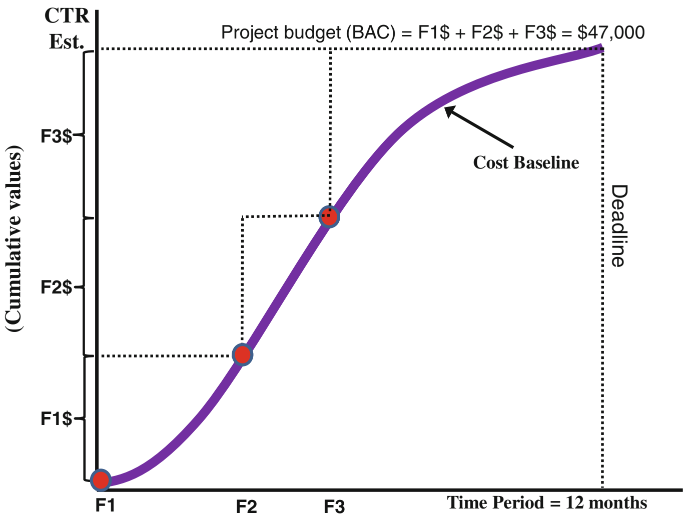

Fig. 15.15 Performance measurement baseline, showing the cumulative values of cost, time and resources

Three activities comprise the project performance evaluation process: data collection, data analysis, and information reporting. The two major approaches used for these activities are earned value analysis and variance analysis. These approaches will be discussed in detail in Sects. 15.5.1 and 15.5.3.

15.5.1 Earned Value Analysis

15.5.2 Elements of Earned Value Analysis

"Earned value is the crystal ball for project cost and schedule forecasting."—Joy Gumz

Earned value analysis was developed in the 1960s as a tool for measuring and evaluating project performance. EVA uses monetary value as the common measure of evaluating project cost and schedule performance over a period of time. According to Fleming and Koppelman (2000), it is still considered the best method to monitor and correct deviation from set target. The structure of earned value analysis is depicted in Fig. 15.16.

Earned value analysis (EVA) is the accepted and preferred tool for measuring and assessing project performance through the integration of technical scope with schedule and cost objectives during the execution phase of a project. It has been used by National Aeronautics and Space Administration (NASA) and government contractors for over 20 years. During the late 1980 s and early 1990s, the tool gained

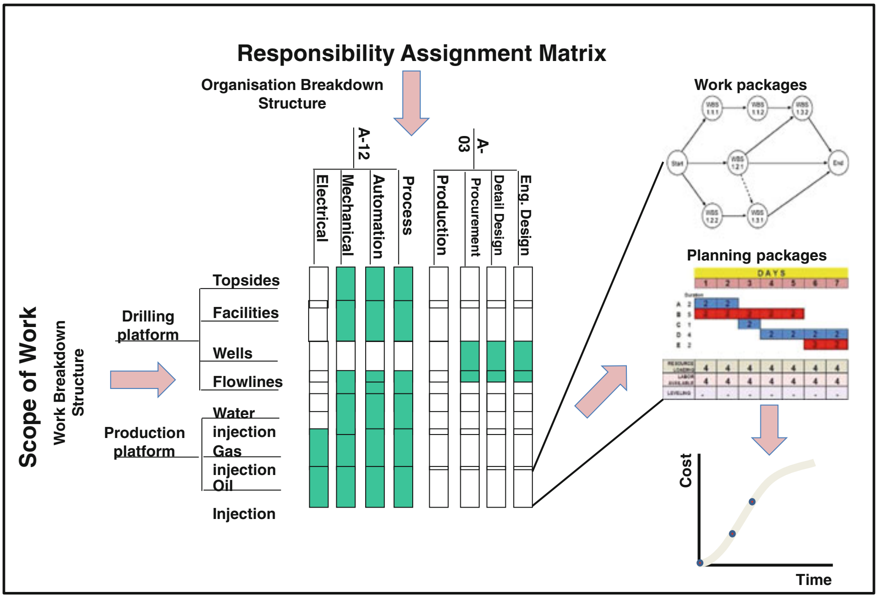

Fig. 15.16 Earned value structure, showing the integration of the WBS, OBS, network diagram and Gantt chart

acceptance in the private sector, particularly the resource (petroleum and mining) sector. EVA provides quantification of technical progress, enabling management to gain insight into project status and project completion costs and schedules.

Even though EVA is considered the most effective way to determine project status and measure project performance, it has not been widely applied or used worldwide. Most companies still use planned cost and actual cost to determine project performance (Anbari 2003). During the execution of projects, a comparison between the money planned to be spent (budget) and the money actually spent (actual cost) is not sufficient to determine the project status and performance. It is necessary to include in the comparison the *actual work accomplished* in order to really understand the actual completion level of a project.

The idea of cost and schedule control that is based on a simple comparison between planned value, earned value and actual performance is illustrated in Table 15.5.

The earned value concept integrates cost, schedule, and work performed by ascribing monetary values to each. It uses the following project parameters to evaluate performance:

- Planned value (PV) or budgeted cost of work scheduled (BCWS);
- Actual cost (AC) or actual cost of work performed (ACWP);
- Earned value (EV) or budgeted cost of work performed (BCWP).

Table 15.5 Budget estimate for carbon capture and storage project

Earned Value Report

Project No.: 20141125 **Date:** 25th November, 2014 **FILE:** 1
Description: Carbon Capture & Storage Project **Page** 1 **of** 1
Prepared by: Ben **Signed:** Ben

	Cumulative-to-Date			Variance		At Completion				
WBS # or Name of Activity	PV (BCWS)	EV (BCWP)	AC (ACWP)	Schedule	Cost	Budgeted (BAC)	Estimated (EAC)	Variance	Critical Ratio	Action Required
Task A	2000	2000	1850		150	2000	1850	150	1.0810811	O.K.
Task B	18000	18000	17200		800	18000	17200	800	1.0465116	O.K.
Task C	2000	1143	4000	-857	-2857	4000	14001	-10001	0.1633061	RED FLAG
Task D	10500	12000	14500	1500	-2500	15000	18125	-3125	0.9458128	O.K.
Task E						2000	2000		#N/A	#N/A
Task F						6000		6000	#N/A	#N/A
									#N/A	#N/A
									#N/A	#N/A
									#N/A	#N/A
									#N/A	#N/A
									#N/A	#N/A
									#N/A	#N/A
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									#N/A	#N/A
									#N/A	#N/A
									#N/A	#N/A
									#N/A	#N/A
									#N/A	#N/A
TOTALS:	32500	33143	37550	643	-4407	47000	53176	-6176	0.9000991	O.K.

NOTE: Negative variance is unfavorable || If Critical Ratio < 0.6, INFORM MANAGEMENT!
( ) = NEGATIVE VALUES

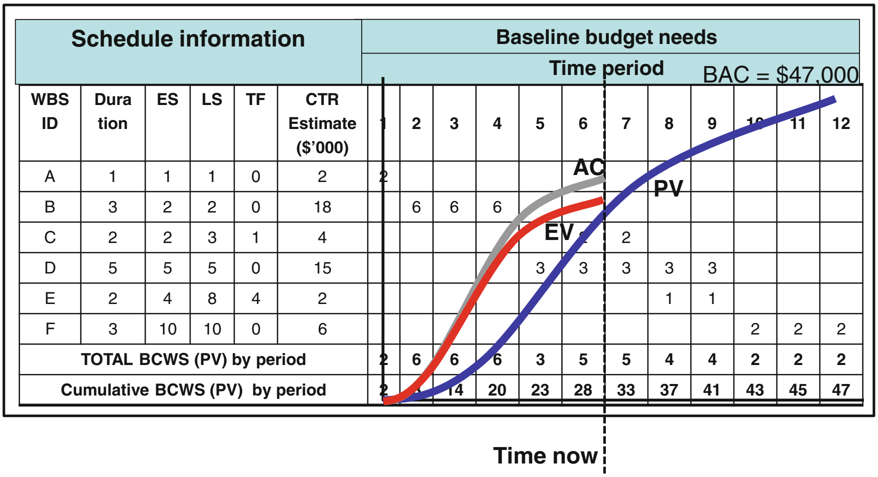
15.5.2.1 Planned Value (PV)

Planned value, otherwise known as the budgeted cost of work scheduled (BCWS) is the cumulative value (in monetary units) of work scheduled to be accomplished in a given period of time (a single control period, or an ordered sequence beginning with the first period).

In simple terms, it is the estimated cost of all the activities to be performed during a project life, or any given time period during the duration of a project. A graphical representation of the planned value is provided by the cumulative cost over time curve shown in Fig. 15.15.

For example, by the status period of July 1, activity A and B are estimated to be 100 % complete. Activity C is estimated to be 50 % complete, while Activity D is estimated to be 70 % complete. Activity E and F are not planned for execution. The planned value (PV) for the project as at July 1 is \$2000 + \$18,000 + \$2000 + \$10,500 = \$32,500 (see Table 15.5 and Fig. 15.17).

Thus the work content scheduled to be accomplished during the first six months of the project is budgeted at \$32,500.



WBS ID	Duration	ES	LS	TF	CTR Estimate ($'000)	1	2	3	4	5	6	7	8	9	10	11	12
A	1	1	1	0	2	2											
B	3	2	2	0	18		6	6	6								
C	2	2	3	1	4						2	2					
D	5	5	5	0	15					3	3	3	3	3			
E	2	4	8	4	2								1	1			
F	3	10	10	0	6										2	2	2
TOTAL BCWS (PV) by period						2	6	6	6	3	5	5	4	4	2	2	2
Cumulative BCWS (PV) by period						2	[illegible]	14	20	23	28	33	37	41	43	45	47

Fig. 15.17 The revised 'S' Curve, showing cumulative budget requirements over time is now plotted on Gantt chart

15.5.2.2 Actual Cost (AC)

Actual cost (AC), which is also called the actual cost of work performed (ACWP), is the cost actually incurred and recorded in accomplishing the work performed within the control period. Like the planned value (PV), it is a plot over time of expenditures. This time, instead of plotting the project's planned expenditures, the project's real expenditures over time are plotted. At the end of each reporting period, we take the total amount of money that was spent on the project during that period and plot it as an addition to the total amount of money that had been spent as of the last reporting period.

AC is perhaps the easiest value to understand because it is clear and straightforward. It is the cumulative amount paid for labour, material, and all other direct costs over a period of time. As can be seen in Table 15.5, a total of $37,550 was spent during the first 6 months to accomplish the work performed.

It is imperative that every expenditure that is made on the project be collected in a timely manner. The timing of the collection of the actual cost of work performed must match the anticipated timing of the expenditures that were planned and plotted on the S-curve. This is very important since, if expenditures are collected early or late in the project in relation to the project plan, the earned value report will show a positive or negative variance when there may really be none!

15.5.2.3 Earned Value (EV)

Earned value (EV), which is also called budgeted cost of work performed (BCWP) is the cumulative sum of the estimated costs of those tasks or parts of tasks that have actually been completed. Another way to define an EV is by estimating the value of work actually performed and compared it with the work planned.

The introduction of earned value concept is the real breakthrough in project performance evaluation. The concept might seem a little hard to understand for a beginner because it is difficult to grasp at first. However, the concept is not as complex as it seems. Simply stated, EV is the value of work that was actually performed.

Looking at the example in Table 15.5, 100 % of activity A is accomplished. Therefore, its EV is equal to the total budget of activity A, which is \$2,000. Similarly, for activity B, EV = \$18,000. However, for activity C, the work performed is only 2/7 (or 29 %) of the activity's estimated work content. Therefore, its EV = \$4,000 × 2/7 = \$1,143. Activity D is 80 % complete, while Activity E and F have not started. The EV figures are summarized as follows:

EV = \$2,000 + \$18,000 + \$1,142.86 + \$12,000 = \$33,143.

Thus, the EV for the 6 months period is equal to \$33,143.

The equation typically used to determine the EV is as follows:

$$EV = \%Complete \times Original\,Budget \tag{15.1}$$

Measurement and evaluation of project performance require a control process consisting of the following four steps;

1. constructing the S-Curve,
2. measuring progress and performance,
3. comparing plan value against actual value, and
4. taking action.

The 'S' curve, similar to the one shown in Fig. 15.15, becomes the base plan, which can be used to measure, evaluate, and control a project performance, using variance analysis and performance indices, respectively.

Following an updated analysis of the network shown in Fig. 15.15, it would be possible to construct a cumulative cost over time curve ('S' curve) as illustrated in Fig. 15.17.

In order to assess financial performance against planned performance as the project proceeds, it is necessary that at each review (stage gate) actual expenditure and planned expenditure are compared with the original estimated cost of the work done. Variance indicators are the most useful tool used for this purpose. This is so because they are measures that closely resemble those traditionally used in the industry and what the senior managers are looking for.

15.5.3 Variance Analysis: Formulas and Their Interpretation

Earned value analysis is used to identify schedule and cost variances that may occur during project execution. The tool for measuring progress and performance of any project include the following:

- Cost variance (CV)
- Schedule variance (SV)
- Variance at completion (VAC)
- Cost performance index (CPI)
- Schedule performance index (SPI)
- Percent complete (PC) and percent spent (PS)
- Estimate at completion (EAC)
- Estimate to complete (ETC)
- Estimated Duration at Completion (EDAC)

We shall discuss each tool for measuring project's progress and performance in detail.

15.5.3.1 Variance Indicators

There are two variance indicators used for measuring progress of a project: cost variance and schedule variance. Both are calculated numbers using the three data values previously mentioned: PV, EV, and AC.

Cost Variance

Cost variance (CV) is the difference between the value of the work actually completed and the amount of money actually spent for the work. CV is calculated by the formula:

$$CV = EV - AC \tag{15.2}$$

Using the data in Table 15.5, for the example:

$$CV = \$33{,}143 - \$37{,}550 = -\$4,407 \tag{15.3}$$

The negative figure indicates the project is over budget. A positive value would indicate the project is under budget, and 0 would indicate it is exactly on budget.

Schedule Variance

Schedule variance (SV) is the difference between the value of the work actually completed and the amount estimated for the work. SV is calculated by using the following equation:

$$SV = EV - PV \tag{15.4}$$

Using the data in Table 15.5:

$$SV = \$33{,}143 - \$32{,}500 = \$643 \tag{15.5}$$

Thus, at the time of the data sample or reporting date, the project is over budget and ahead of schedule as indicated by a positive SV. A negative value would indicate the project is behind schedule, and 0 would indicate it is on schedule.

However, the equation for schedule variance is not of much use until it is amended to report the schedule variance as a percentage. Once the schedule variance is known in terms of a percentage (positive or negative decimal value), the percentage can then be multiplied by the time since project inception to determine the schedule variance in any unit of time, e.g., days, weeks, or months (Havranek 1999).

The equation for schedule variance percent (SVP) is calculated as follows:

$$SVP = \frac{SV}{PV} = \frac{EV - PV}{PV} \tag{15.6}$$

While the equation for schedule variance time (SVT) is calculated as follows:

$$SVT = SVP \times Time\ now \tag{15.7}$$

In this way, schedule variance (SV) presents an overall assessment of all work packages in the project scheduled to date. Thus, measures of the physical and financial performances are separated.

The S-curve shown in Fig. 15.17 extends from zero at project start to \$47,000 at project completion. With this graphing approach, the cost variance is indicated by the vertical distance between the curves for EV and AC, which shows a cost overrun of \$4,407. The schedule variance is indicated by the horizontal distance between EV and PV, which shows that the project is 0.12 month (or 3.6 days) ahead of schedule. This is calculated as follows:

$$SVT = \frac{\$33{,}143 - \$32{,}500}{\$32{,}500} \times 6 = 0.02 \times 6 = 0.12\ month\ (3.6\ days) \tag{15.8}$$

15.5.3.2 Performance Indices

The cost and schedule performance indices are especially good for communicating progress and status reporting. The popular performance indices include:

- cost performance index;
- schedule performance index;
- percent complete and percent spent;
- completion estimates.

Cost Performance Index

The cost performance index (CPI) is calculated by dividing the value of the work actually performed by the AC of the work:

$$CPI = EV/AC \tag{15.9}$$

Using the data in Table 15.5 for the example:

$$CPI = \$33{,}143/\$37{,}550 = 0.88 \tag{15.10}$$

This number is interpreted to mean that for every dollar spent on the work, the return is only 88 cents in value. The following can be used as rule of thumb:

- if CPI is less than 1, then project is below budget, i.e., money spent is more than what is being returned in value;
- if CPI is greater than 1, then project is overspent, i.e., project is worth more than money spent;
- if CPI is equal to 1, then project is exactly on budget.

CPI is a practical forecasting tool because it can be plotted and trends determined from the data. Many project managers develop a control chart layout for the CPI data and use it as a control mechanism by maintaining the CPI curve within a pre-agreed-upon upper and lower control limit, much as is done with quality control charts and their upper and lower standard deviation lines.

Schedule Performance Index

The schedule performance index (SPI) is calculated by dividing the value of the work actually performed by the planned cost of the work:

$$SPI = EV/PV \tag{15.11}$$

Again, using the data in Table 15.5 we get:

$$SPI = \$33{,}143/\$32{,}500 = 1.01 \quad (15.12)$$

This index value is interpreted as showing how well the actual performance of the project is doing against the plan. The following can be used as a rule of thumb:

- if the SPI is greater than 1, then the project is ahead of schedule;
- if the SPI is less than 1, then the project is behind schedule;
- if the SPI is equal to 1, then the project is on schedule.

The CPI and SPI indices shown above indicate that the example project is below budget, but slightly ahead of schedule.

15.5.3.3 Percent Complete and Percent Spent

The two percent calculations (percent complete and percent spent), are especially important for communicating project performance to the senior management and other stakeholders, when comparing plan against actual estimates. Almost all status or progress reports require these calculations because of their importance to the overall organizational health and because of future planning ramifications.

Percent Complete

Percent complete (PC) is calculated by dividing the value of the actual work performed (EV) by the project budget at completion (BAC) or by the latest revised estimate at completion (EAC), which will be discussed shortly.

The PC is calculated by:

$$PC = EV/BAC \quad (15.13)$$

For example, looking at Table 15.5 and Fig. 15.15:

$$PC = \$33{,}143/\$47{,}000 = 0.71 \quad (15.14)$$

This means the example project, as at July 1, is a little over 70 % complete.

Percent Spent

The percent spent (PS) is calculated by dividing the actual expenditures (AC) to date by the BAC:

$$PS = AC/BAC \quad (15.15)$$

For the example:

$$PS = \$37{,}550/\$47{,}000 = 0.80 \tag{15.16}$$

This means that 80 % of the budget has been spent. These calculations are not only important for communicating with the stakeholders, but they are also very important to the project manager because he or she needs to be able to judge whether there is enough left in the budget to finish the project.

15.5.3.4 Completion Estimates

Completion estimates are used to determine how a project is doing compared to the plan and how close the plan is likely to be compared to the original projections (S-curve). There are three key completion estimates required for the calculation: the estimate at completion (EAC), the variance at completion (VAC), and estimate to complete (ETC).

Estimate at Completion

Estimate at completion (EAC) is the best estimate of the total cost at the completion of the project. As project progresses, data improve and estimates for the baseline become more accurate. Since schedule-cost baseline (the S-curve) is just an estimate, it is important to determine how good the estimate was and whether the budget, or schedule or quality need to be refined. This is calculated as follows:

$$EAC = \frac{AC}{EV} \times BAC \tag{15.17}$$

Equation 15.17 can also be written as:

$$EAC = \frac{BAC}{CPI} \tag{15.18}$$

Using the BAC from the example data in Table 15.5 and the calculated CPI, the new EAC is calculated as follows:

$$EAC = \frac{\$47{,}000}{0.88} = \$53{,}409 \tag{15.19}$$

Variance at Completion

Variance at completion (VAC) is the difference between the original estimate and the new EAC for a project. It is calculated as follows:

$$VAC = BAC - EAC \tag{15.20}$$

For the example provided:

$$VAC = \$47{,}000 - \$53{,}409 = -\$6409. \tag{15.21}$$

Estimate to Complete

The estimate to complete (ETC) is an estimate of the additional money that will be required to complete the project, if the project performance continues at same rate as of now. It is calculated from the estimate at completion that was discussed earlier. The ETC is calculated by simply comparing the latest EAC to the amount of money actually spent to date:

$$ETC = EAC - AC \tag{15.22}$$

From the project example shown, the ETC can be calculated thus:

$$ETC = \$53{,}409 - \$37{,}550 = \$15{,}859$$

This means that the project example will require \$15,859 to pay for all the remaining work.

15.5.3.5 Estimated Duration at Completion

Estimated duration at completion (EDAC) is achieved by dividing the original duration estimate (ODE) by the schedule performance index (SPI). This is calculated as follows:

$$EDAC = \frac{ODE}{SPI} \tag{15.23}$$

For the example provided:

$$EDAC = \frac{12}{1.01} = 11.88\ months \tag{15.24}$$

This shows that the project is 0.12 months, or 3.6 days, ahead of schedule as per current status report (see Eq. 15.8), and if situation remains the same, then the project will complete by 11.88 months.

15.5.4 Project Management Software

Project management software is a term covering many types of software, including estimation, planning, scheduling, cost control and budget management, resource allocation, collaboration software, communication, quality management and documentation or administration systems, which are used to deal with the complexity of large projects. Project management software has the capability to help plan, organize, and manage resource pools and develop resource estimates. For example, project management software for scheduling provides the ability to track planned dates versus actual dates, and to forecast the effects of changes to the project schedule. Project management estimating software applications, computerized spreadsheets, simulation, and statistical tools are becoming more widely accepted to assist with cost estimating. Such tools can simplify the use of some cost estimating techniques and thereby facilitate rapid consideration of cost estimate alternatives. Depending on the sophistication of the software, resource breakdown structures, resource availability, resource rates and various resource calendars can be defined to assist in optimizing resource utilization (PMI 2008).

Project management software is often used to monitor the three earned valued management (EVM) dimensions (present value, earned value, and actual cost), to display graphical trends, and to forecast a range of possible final project results.

Most project management software provides managers with the following benefits:

- Project visibility—shows the project as a whole, allowing one to accurately predict the results of project constraints (scope, time, costs, etc.).
- Resource visibility—shows the resources available in a project, allowing one to properly distribute and prioritize work.
- Metric visibility—shows the current status of certain elements of a project in relation to the end goal.

15.6 Integrating WBS with Cost and Schedule Control System

Earned value analysis is accepted worldwide as a preferred tool for monitoring and controlling a project. It is therefore an important tool for evaluating the performance of an environmental restoration/remediation project.

It has been used by government contractors and contractors/project managers in the private sectors for over 20 years. It is also the method of choice for the project management institute (PMI) as an efficient tool for evaluating the performance of any complex project.

Environmental management tools discussed in earlier chapters, are combined with geospatial tools (e.g., remote sensing, Web GIS, GNSS, and photogrammetry) and project management tools (e.g., WBS, RAM, Gantt chart, and network diagram) to develop project performance measurement baseline, otherwise known as "S-curve" (see Fig. 15.16). How scope change in terms of space, time and scale (see Fig. 3.15) reflects in the work breakdown structure (WBS), schedule, cost and performance measurement baseline is illustrated in Fig. 15.18.

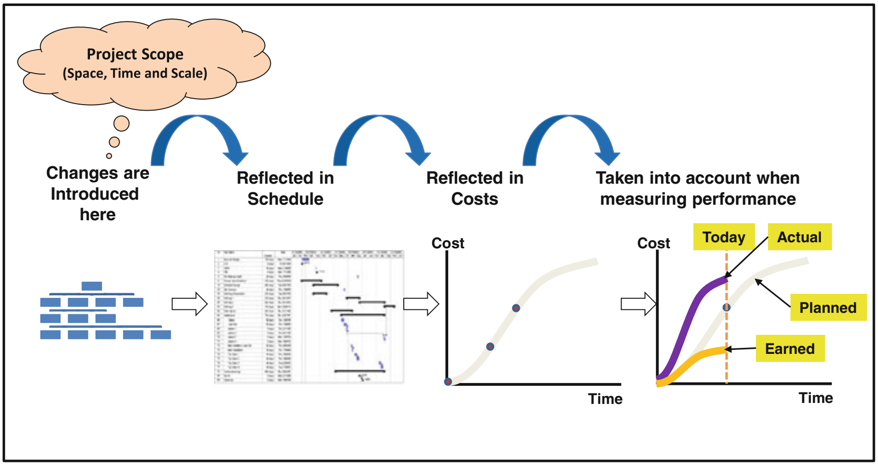


Fig. 15.18 Earned value analysis process, showing how changes in project scope is reflected in the WBS, Gantt chart, and performance baseline

The primary advantage of earned value analysis is that not only can the actual costs of a project be measured and tracked against the projected cost plan, but scheduled progress can also be measured in a way that clearly shows budget and schedule progress. Moreover, earned value analysis provides accurate forecasting, so that schedule and budget can be adjusted to maintain the planned projections (Taylor 2008).

15.7 Linking Project Management Tools to PMBoK

Every project manager needs tools to manage risks, tract costs, or plan a project. The more these tools are tailored to the project manager's needs and made consistent throughout the organisation, the more effective and efficient they are.

Since PMBoK is a widely accepted project management guide developed by the Project Management Institute, it is logical to link project management tools covered in this book with PMBoK's project management processes and knowledge areas (Milosevic 2003). This is illustrated in Fig. 15.19. Symbols in parentheses are used as a key for the following project management processes:

- Initiation process group (Init.)
- Planning process group (Plan.)
- Execution process group (Exec.)
- Controlling process group (Cont.)
- Closing process group (Clos.).

Chapt.	Project Management (PM) Tools		Can be Used in PMBoK Project Management Processes					Can be Used in PMBoK Project Management Knowledge Areas									
			1 Init.	2 Plan.	3 Exec.	4 Cont.	5 Clos.	1 Int.	2 Scope	3 Time	4 Cost	5 Qual.	6 HR	7 Com.	8 Risk	9 Proc.	10 Stake.
Sect. II	Initiation Tools	Brainstorming	√					√					√				
		Stakeholder Matrix	√	√				√					√	√			√
		SWOT Analysis	√	√				√	√						√		
		Portfolio Selection	√						√						√		
Sect. III	Planning Tools	Affinity diagram		√				√				√					
		The WBS		√				√	√							√	
		Gantt Chart		√				√		√							
		Make-or-Buy Analysis														√	
		Network Diagram		√				√		√							
Sect. IV	Implementation Tools	Milestone Chart				√				√	√			√			
		Pareto Chart			√	√						√					
		Ishikawa Diagram			√	√						√			√	√	
Sect. V	Monitoring Tools	Earned Value Analysis				√	√			√	√			√			
		Variance Analysis				√				√	√			√			
		PM Software		√		√	√	√	√	√	√	√		√	√	√	

Fig. 15.19 Inking project management tools to PMBoK

The following symbols in the parentheses are used as a key for the ten knowledge areas of PMBoK:

- Project integration management (Int.)
- Project scope management (Scope)
- Project time management (Time)
- Project cost management (Cost)
- Project quality management (Qual.)
- Project human resources management (HR)
- Project communication management (Com.)
- Project risk management (Risk)
- Project procurement management (Proc.)
- Project stakeholder management (Stake.).

15.8 Concluding Remarks

The project management toolbox discussed in this chapter was developed for simple applications. The tools are geared toward people and project teams and can be used by project managers in all ten knowledge areas of the project management body of knowledge (PMBoK) to contribute in a highly collaborative fashion to bring project success to fruition. The toolbox includes a collection of examples of the tools applied in real projects as a reference and to provide guidance.

This chapter presents fourteen project management tools; each one with a different purpose. Therefore, these tools do not compete with each other for the project manager's attention. Rather, they can be viewed as a suite of tools for use in the initiation, planning, executing, controlling and close-out processes. Brainstorming is used to bring out the ideas of each project team member and present them in an orderly fashion to the rest of the team. Affinity diagram gathers the ideas and organise them into groups based on their natural relationships. SWOT analysis evaluates the internal (strengths and weaknesses) and external (opportunities and threats) issues in an environmental project and enables a meticulous analysis of the issue, its potential causes, and possible solutions. A significant help in this effort is the Ishikawa or cause-effect diagram, designed to identify, relate, and graphically display causes to a problem. Concentrating on those causes of the problem, which if removed will have the largest improvement impact, is what the Pareto chart enables.

There is a whole family of software programs (e.g., MS Excel and MS Project by Microsoft, SureTrak, WinSight and Primavera Project Planner Enterprise (P3e) by Primavera, Crystal ball by decisioneering, @Risk and precision tree by Palisade) specifically designed to help with managing environmental projects. Although they speed up many time-intensive tasks, one should not rely on them without understanding the concepts of scheduling, risk, quality, and other aspects of project management that underlie them. Indeed, software tools, no matter how complicated they look, can never take the place of human thought and talents. Using software without understanding, is tantamount to letting a baby play with a calculator. Numbers are keyed in and calculations are made, but they do not do anyone any good.

References

Anbari FT (2003) Earned value project management method and extensions. Proj Manag L 34(4):12–23

Brassard M (1988) The memory jogger, a pocket guide of tools for continuous improvement. GOAL/QPC, Methuen

Brassard M (1989) The memory jogger plus+. Goal/QPC, Methuen, pp 17–39

Campbell JM (2001) Analyzing and managing risky investments, First edn. John M. Campbell, Oklahoma, 500 p

Despeisse M (2010) Zero carbon manufacturing through material energy and waste process flow modeling, MSc thesis, Cranfield University, Cranfield

Edwards RA, Hewett TA (1993) Applying financial portfolio theory to upstream investment decision-making paper SPE 49095 presented SPE annual technical conference and exhibition held on New Orleans, Louisiana, 27–30 September, 1998

Esty DC, Winston AS (2009) Green to gold: how smart companies use environmental strategy to innovate, create value, and build competitive advantage. Wiley, Chichester

Fleming QW, Koppelman JM (2000) Earned value project management, 2nd edn. Project Management Institute, Pennsylvania

Gregory FH (1992) Cause, effect, efficiency and soft systems models, warwick business school research paper no. 42 (ISSN 0265–5976), later published in J Oper Res Soc 44 (4):333–344

Grimble R, Wellard K (1996) Stakeholder methodologies in natural resource management: a review of principles, contexts, experiences and opportunities. Agric Syst 55(2):173–193

Haugan GT (2002) Effective work breakdown structures. Management Concepts Inc, Vienna, 100 p

Havranek TJ (1999) Modern project management techniques for the environmental remediation industry. CRC Press, Boca Raton, 456 p

Hightower ML, David A (1991) Portfolio modeling: a technique for sophisticated oil and gas investors, paper 22016 presented at the SPE hydrocarbon economics and evaluation symposium held in dallas, Texas, April 11 12, 1991
Howden PF (2009) A critical-stakeholder analysis process, practice change tools and frameworks booklet no. 1, 2nd edn. Department of Primary Industries, Bendigo, available on request from the authors
Humphrey A (2005) SWOT analysis for management consulting, SRI Alumni Newsletter
Ishikawa K (1976) Guide to quality control. Asian Productivity Organization. ISBN 92-833-1036-5
Klastorin T (2003) Project management: tools and trade-offs, 3rd edn. Wiley, New Jersey. ISBN 978-0-471-41384-4
Koch R (2001) The 80/20 principle: the secret of achieving more with less, London
Lozano M, Valles J (2007) An analysis of the implementation of an environmental management system in a local public administration. J Environ Manag 82:495–511
Markowitz HM (1952) Portfolio selection. J Financ 7(1):77–91
Markowitz HM (1959) Portfolio selection: efficient diversification of investments. Yale University Press, New Haven
Milosevic DZ (2003) Project management toolbox: tools and techniques for the practising project manager. Wiley, New Jersey, 584 p
Norman E, Brotherton S, Fried R (2008) Work breakdown structures. Wiley, Hoboken, 67 p
Orman M, Duggan TE (1998) Applying modern portfolio theory to upstream investment decision-making, paper SPE49095 presented SPE annual technical conference and exhibition held on New Orleans, Louisiana, 27–30 September, 1998
Othieno H, Awange J (2015) Energy Resources in Africa: distribution, opportunities and challenges. Springer international publications, Heidelberg
Pinto JK (2013) Project management: achieving competitive advantage, 3rd edn. Pearson, London, 528 p
Plummer F (2011) Project engineering: the essential toolbox for young engineers. Butterworth-Heinemann, Oxford, 240 p
PMI (2006a) Practice standard for work breakdown structures, global standard. Project Management Institute, Pennsylvania, 111 p
PMI (2006b) The standard for portfolio management. Project Management Institute, Newtown Square
PMI (2008) A guide to the project management body of knowledge (PMBOK guide), 5th edn. Project Management Institute, Newtown Square
PMI (2011) Practice standard for earned value management, second edn. Project Management Institute, Newtown Square, 56 p
PMI (2013) A guide to the project management body of knowledge (PMBOK guide), 5th edn. Project Management Institute, Newtown Square
Scholtes PR, Jeiner BL, Streibel BJ (1988) The Team Handbook, pp. 2–25, Madison, WI: Joiner Associates
Sholarin EA (1989) Goal programming approach to planning science and technology in the Nigerian petroleum industry, PhD thesis, Moscow State University of Oil and Gas, Russia
Sholarin EA (2007) Integrated project management for hydrocarbon portfolio analysis and optimization. J Pet Technol 59(2)
Shtub A, Bard JF, Globerson S (2005) Project management: processes, methodologies and economics. Pearson Education Inc, Upper Slade River
Taylor JC (2008) Project scheduling and cost control: planning, monitoring and controlling the baseline. J. Ross Publishing Inc, Newcastle
Vaidyanathan G (2013) Project management: process, technology, and practice. Pearson, London
Wideman RM (1991) A Framework for project and program management integration. The PMBOK handbook series, vol 1, Project Management Institute, Drexel Hill, PA, III-5

Chapter 16
Project Management Techniques

> *All things are created twice; first mentally; then physically. The key to creativity is to begin with the end in mind, with a vision and a blue print of the desired result*
>
> —Stephen Covey

16.1 Introduction

Tools and techniques are widely used in many human endeavors, such as engineering, construction, banking, manufacturing, marketing, health care, sales, transportation, information technology, research and development, academics, legal, political and government establishments, just to mention a few. Despite its successful application, these methods are yet to be applied to environmental protection, conservation, and remediation industries for sustainable development. In many situations, the on-time completion of any project is of paramount importance. Delayed or unsuccessful projects not only translate to monetary losses but they also impede subsequent undertakings.

The execution of any project, and these include environmental projects, involves the coordination of many activities. Projects of short duration involving relatively few resources can be planned and controlled by experienced staff without the aid of formal planning tools or techniques. However, more scientific approach is necessary if the project requires the completion of numerous inter-related activities, which draw upon a common set of finite resources over extended period of time.

Project management process means planning the work and then working the plan (Meredith and Mantel 1999). Planning determines what needs to be done, who will do it, how long it will take, and how much it will cost. The result of this effort is a *baseline plan*. Taking the time to develop a well-thought-out plan is critical to the successful accomplishment of any project. Many projects have overrun their budgets, missed their completion dates, or only partially met their requirements because there was no viable baseline plan before the project was started. Careful planning is therefore required to ensure that a project is completed on time and within budget.

E.A. Sholarin and J.L. Awange, *Environmental Project Management*,
Environmental Science and Engineering, DOI 10.1007/978-3-319-27651-9_16

In this chapter, techniques to assist in the planning of environmental projects are considered. These techniques include Delphi technique, scope planning techniques, cost estimating techniques, activity scheduling techniques, and resource scheduling techniques. The use of these techniques to assist in scheduling activities and resources so that the project finishes within the minimum feasible time and with optimum number of resources is demonstrated.

The ultimate benefit of implementing project management techniques is having a satisfied customer—whether in form of an individual, a community or an organisation. Completing the full scope of work of the project in a quality manner on time and within budget provides a great feeling of satisfaction. When projects are successful, everybody wins!

16.2 Delphi Technique

Delphi technique is a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem (Linstone and Turoff 1975, p. 3). The method entails a group of experts who anonymously reply to questionnaires and subsequently receive feedback in the form of a statistical representation of the "group response", after which the process repeats itself. It is used most frequently to integrate the judgments of a group of experts. The goal is to reduce the range of responses and arrive at something closer to expert consensus. Three elements make up the Delphi technique;

1. sequential questionnaires,
2. regular feedback to participants, and
3. anonymity of participants.

The advantages of using Delphi technique are many, which include the following:

- More participants can be involved than a face to face method allows.
- The time and cost of participants travelling to meetings is saved, while still enabling their participation.
- The anonymity of participants is preserved. This can avoid self-censorship, and give participants the flexibility to modify their views as they learn from others, without the social pressure that exists in face to face meetings The remote process also avoids negative group influences such as dominating members and political lobbying.
- Provides a structured way for a group of people to make decisions in a political or emotional environment about complex problems.
- The Delphi technique helps reduce bias in the data and keeps any one person from having undue influence on the outcome.

However, as with all methods, there are also disadvantages:

- The process is time consuming to coordinate and manage. Dunham (1998) states that "coordination of the Delphi technique using email with 20 participants and the processing of three questionnaires could utilise 30–40 h of the coordinator's time".

- It can be difficult to maintain active participation by participants the whole way through, and so drop-outs are more likely than at one-off meetings.
- The decision-making process is less transparent than face-to-face meetings, and can be more easily influenced by the coordinator. This can lead to less trust in the process and outcome/s by participants.

Delphi Technique Procedure

Step 1 From the outset, determine the issue to be addressed and decide if Delphi is the most appropriate method.

Step 2 Form a team to organise, coordinate and oversee the Delphi (this will involve selecting the participants, and overseeing the data collection and analysis process). The coordinator should be independent. Consider having some participants, or stakeholders involved in overseeing the process to improve its transparency.

Step 3 Decide who needs to be involved in the process. The number of people involved will depend on the purpose and the resources available.

Step 4 Enlist participants and clearly outline in verbal and written form what is expected of them. It is important that they know the expected time commitment at the beginning so that they are more likely to stay involved in the whole process. Questionnaires are distributed to participants (either by email, post or fax). Responses to the first questionnaire are summarised and used to develop the second questionnaire, which seeks agreement, disagreement and insights from the same pool of participants. The process goes on to third and subsequent questionnaires until no new opinion emerges.

The process typically builds consensus or agreement by participants altering their views between successive questionnaires to align with responses from others, or by establishing a new common view.

16.3 Scope Planning Techniques

A project scope is the sum of work performed to deliver a product, service or result (PMI 2013, p. 4). It includes all of the *deliverables* and all of the *activities* needed to create the deliverables.

Scope planning is the process of progressively elaborating the work of the project, which includes developing a written scope statement that includes the project justification, the major deliverables and the project objectives. Scope planning links with schedule planning and resource/budget planning since each task or activity must be scheduled to occur at a particular time in the project and each task or activity requires that an individual or organization be assigned to do the work.

Scope planning techniques include decomposition of the work breakdown structure (WBS), organisation breakdown structure (OBS), and the risk breakdown structure (RBS).

16.3.1 Decomposition of Work Breakdown Structure (WBS)

Decomposition is a project management technique used for dividing each project deliverable into smaller and smaller pieces until there is enough detail to support scheduling, estimating, and control (see e.g., Kerzner 1984; Havranek 1999; Miller 2009; Vaidyanathan 2013). Decomposing a project into a WBS framework can be accomplished in two ways: the tree diagram format or indented outline format (see Figs. 16.1 and 16.2). The main benefit of developing a WBS in the tree diagram format is that it graphically displays the project hierarchy and shows how the work packages add up to form sub-deliverables, major deliverables and the final deliverable, thereby describing the entire project. However, the major disadvantage is that it becomes too large to be useful.

An example of the WBS in tree diagram format is shown in Fig. 16.1. The highest breakdown required to complete the carbon capture and sequestration project, otherwise known as the major deliverables or planning level will show main processes and milestones for each of the sub-deliverables. As carbon capture, transportation, storage and project management are distinct phases of the major deliverable, these are placed at Level 1 of the WBS. This fits not only with the progression of the work, but also with the contracting strategy; i.e., different contractors for conducting CO_2 capture, pipelines, storage site characterization, and so on may be employed or used.

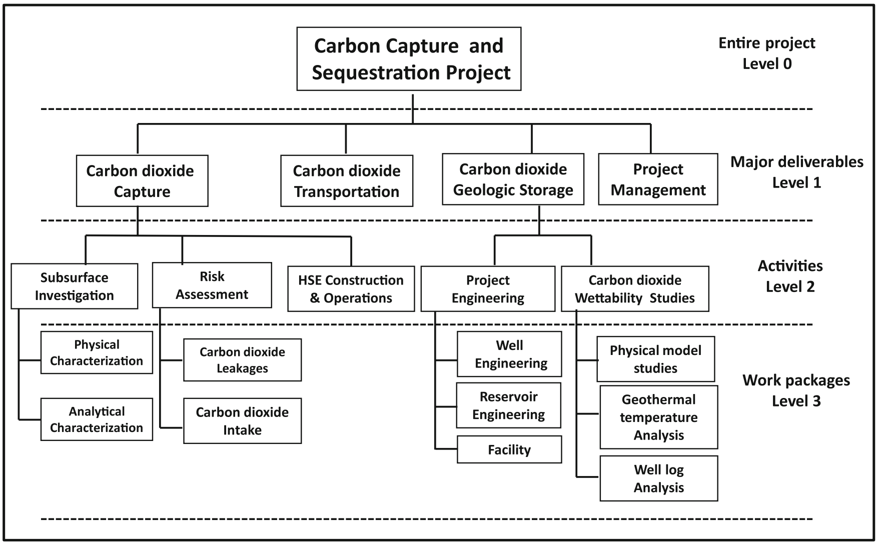


Fig. 16.1 WBS for CO_2 sequestration project in tree diagram (chart) format

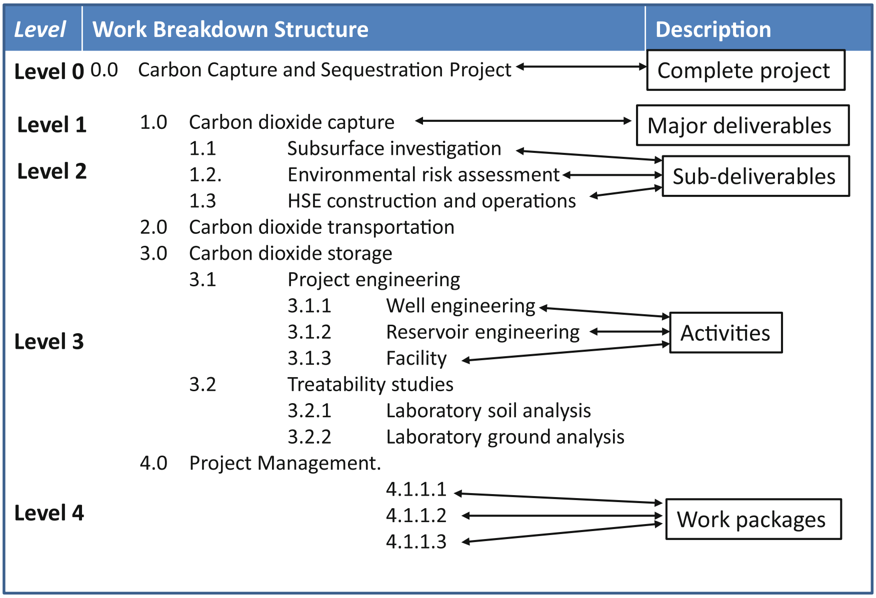


Fig. 16.2 WBS for CO_2 sequestration project in tabular (indented outline) format

For a project of this magnitude, an additional level of planning detail is required, where each of the sub-deliverable is broken down one level further to address the main systems, facilities and selected project management processes, e.g., environmental compliance, government permit for soil excavation in order to conduct laboratory soil analysis, etc. Ultimately the WBS cascades down to the work package level, and all tasks and elements in the structure have an identification code. The "cost account" is the focal point because all budgets, work assignments, time, cost, and technical performance come together at this point.

An example of a work breakdown structure with an indented outline format is shown in Fig. 16.2. The figure shows WBS with four levels: project level (level 0), deliverable level (level 1), subdeliverable level (level 2), task level (level 3), and finally, the work package level (level 4).

The sample WBS shown above seems to be somewhat easy to construct and understand. However, don't be deceived by the simplicity. To create a good and workable WBS, it is important to first understand both the project and its scope, and incorporate the needs and knowledge of the stakeholders. Many project managers have found that it's better to focus on getting the top levels done well to avoid being distracted by too much detail.

Another concern when creating WBS is how to organize the components of the structure in such a way that it provides the basis for the project schedule and cost baseline. The trick is to focus on what work needs to be done and how it will be done, not when it will be done or how much it will cost. In other words, the tasks do not have to be developed as a sequential list of steps. Rather the lower tasks should be seen as the outcome of the upper tasks.

16.3.2 *Decomposition of Organisation Breakdown Structure (OBS)*

Project organizations can be broken down in much the same way as the work or product can. The organisation breakdown structure (OBS) is created to reflect the strategy for managing various aspects of the project and shows the hierarchical breakdown of the management structure.

An example of a typical OBS is shown below where the company is divided, firstly by type of engineering emphasis then by division or department and then to operations. The project proposed a commercial demonstration of advanced technologies that would capture and sequester CO_2 emissions from an existing hydrogen production facility in an oil refinery into underground formations in combination with enhanced oil recovery (EOR).

The company's four directors are each head of a project team which comprise of the project's key focus areas;

1. capture,
2. transport and storage,
3. project office and governance, and
4. stakeholder management.

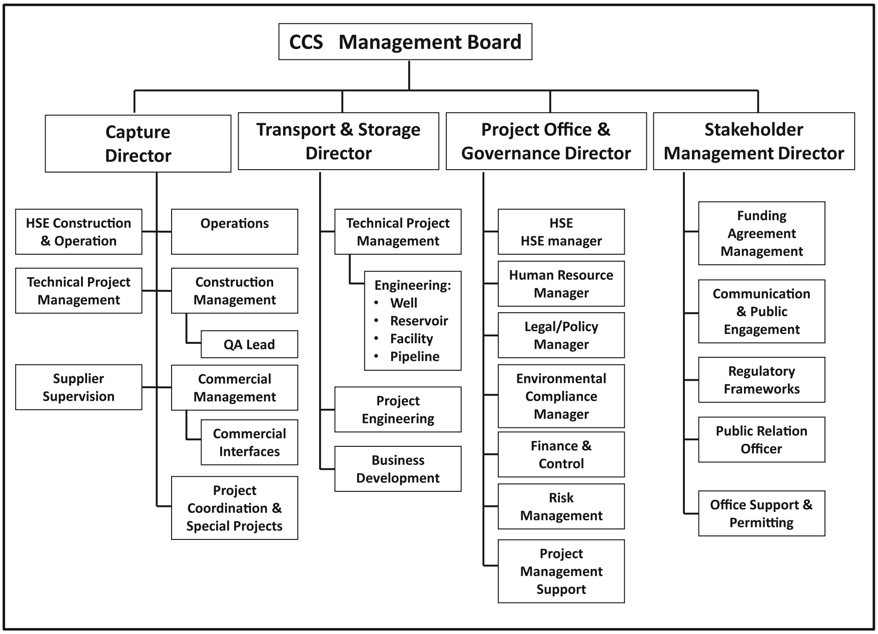


Fig. 16.3 An OBS for CO_2 sequestration project: The company's four directors are head of project team, comprising of carbon capture, sequestration, administration and external support services

An example of an organizational breakdown structure for CO_2 capture and sequestration is shown in Fig. 16.3. The organization revolves around a work package breakdown, subdivided by tasks that are then built up to a project-oriented structure. This work package breakdown has advantages for accounting and reporting purposes.

16.3.3 Decomposition of Risk Breakdown Structure (RBS)

When planning a project to meet targets for cost, schedule, or quality, it is useful to identify likely risks to the success of the project. A risk is any possible situation that is not planned for, but that, if it occurs, is likely to have a positive or negative effect on one or more project objectives such as scope, schedule, cost and quality. For example, an established project team plans for the work to be done by its staff, but there is the risk that an employee may unexpectedly leave the team.

Following the concept of the work breakdown structure (WBS), the risk breakdown structure (RBS) provides a means for the project manager and risk manager to structure the risks being addressed or tracked. Just like the WBS, the risk breakdown structure (RBS) is a hierarchical representation of risks according to their risk categories. If used correctly, the RBS provides a vehicle for risk analysis, reporting and risk comparison across projects. It is also a very important tool for risk identification and for performing “what-if” analysis.

Once the project team has created RBS for their project, individual risks can be identified. The output of risk identification phase can then be used as an input to qualitative risk analysis, where probabilities, priorities and impacts are determined. For more discussion on qualitative risk analysis (QRA), see Fig. 7.1 (environmental risk management framework) on p. 141.

16.3.4 Integrating the WBS with the OBS and RBS

An integral part of the work breakdown structure (WBS) is to define the organisational units responsible for performing the work. In practice, the outcome of this process is the organisation breakdown structure (OBS), such as the one shown in previous section.

The organisational breakdown structure used on a carbon capture and storage (CCS) project will vary with time across the project life cycle, moving from a reservoir engineering emphasis (and marketing, if a gas project) to a well engineering and facilities engineering emphasis and then to a carbon storage emphasis. This change of emphasis with time does not mean that well, facilities and operating engineers are not required in the early stages of the life cycle nor, that reservoir engineers, well engineers and production engineers are not required during the operating stage of the project. In fact, it is vital that all disciplines are involved or engaged in the project from the very outset and thereafter throughout the project life cycle. The design of the OBS in any phase of the project life cycle will depend primarily on three issues;

- work breakdown structure (WBS),
- contracting strategy, and
- project structure.

The WBS needs to be developed as early as possible and, during the early phases of the life cycle, will include both hardware headings (e.g., wells, topsides, etc.) and non-hardware headings (e.g., marketing, government/JVP approvals etc.). Later, the WBS will primarily be hardware driven.

Contracting strategy (the numbers and types of contracts) derived from the WBS is unlikely to have a significant influence on the organisational structure before the completion of the basis of design. After this, it will become a primary factor in the shape of the organisation.

The project structure (location, size, complexity, government policy) will influence the contracting strategy and, through this, and also directly, influence the organisational needs. The resulting intersection between the WBS and the OBS in the WBS/OBS matrix identify the unique activities which need to be managed (see Fig. 16.4).

The OBS addresses the following aspects;

- work organisation establishment,
- roles and responsibilities definition,
- required competencies definition,
- team members selection, and
- external resources identification.

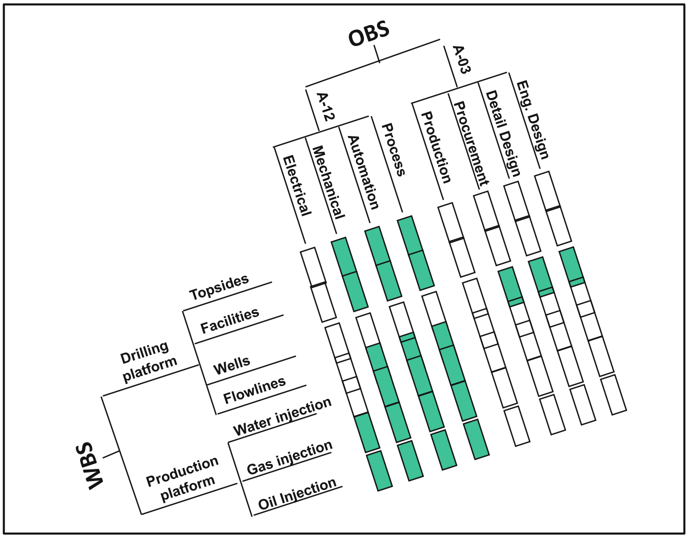


Fig. 16.4 The WBS/OBS Matrix: The *green* colours depict where role and responsibility of a team member intersects with the task to be done

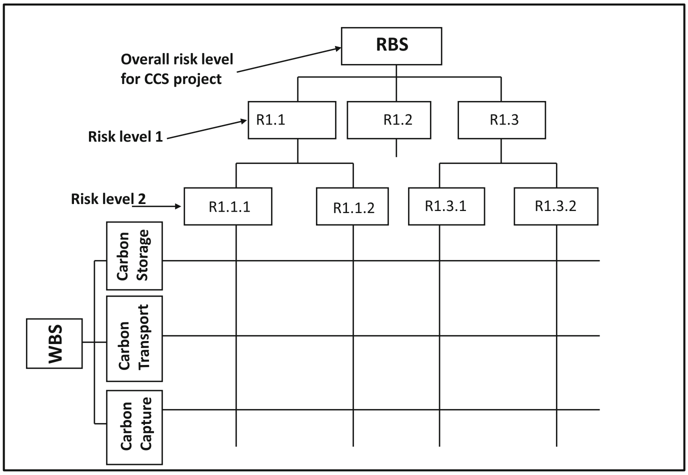


Fig. 16.5 An example of RBS/WBS Matrix for a CCS Project, where each task is matched with its associated risk

Activities and work packages (see Fig. 16.1) vary in their criticality to the success of the project. For instance, use of a totally new technology or inexperience staff will require more management attention than a well-tested and efficient technology or staff. In the same context, similar critical path activities in the project plan need more attention than activities with substantial float, and so on (this is explained in detail under scheduling technique section). Thus the activities and work packages need to be examined for all their criticalities, such as safety, cost, schedule, resources, risks, quality, etc., and the organisation structure and responsibilities shaped to manage these.

The risk breakdown structure (RBS) can be created in a similar manner to the OBS and mapped over the WBS (see Fig. 16.5).

16.4 Cost Estimating Techniques

Estimating project cost is a challenging process that can resemble an art as much as a science. One key for developing cost estimates is to first recognise the need to cost out the project on a disaggregated basis, using the cost breakdown structure (CBS) template. That is, to break the project down by deliverable and work package as a method for estimating task-level costs. For example, rather than attempt to create a cost estimate for completing a deliverable of four work packages, it is typically more accurate to first identify the costs for completing each work package individually and then create a deliverable cost estimates.

Cost estimating refers to estimating the cost of each of the project work packages (PMI 2013). It is the second process in project cost management, which involves determining the unit cost for each of the assigned resources. This information is usually retrieved from the company's cost, time, and resource (CTR) estimates, laboratory analytical fee schedules or subcontractor quotes. It is common to associate cost estimating only with the proposal process. However, cost estimates can be provided to the customer for reasons other than a proposal (i.e., feasibility studies). There are essentially three common type of cost estimation: rough order of magnitude (ROM), budget estimate, and definitive estimate.

- **Rough Order of Magnitude (ROM)**
  Rough order of magnitude (ROM) estimate, sometimes referred to as *ballpark estimate*, is an approximate estimate, made when either time or detailed information is scarce. An ROM estimate is usually made during the early stages of an expenditure project or program. It is an approximate historical estimate, which is prepared without detailed knowledge of the project. The ROM is sometimes called *preliminary*, *conceptual*, *factored* or *feasibility* estimate.
  Project managers often use this estimate when considering appropriate engineering solutions for a particular environmental problem (e.g., hazardous waste, treatment of contaminated soil and groundwater), while senior management looks at this estimate to make decisions on which projects are cost effective and for cost-benefit analysis. When estimating budget cost for a project, there is an uncertainty on the precise content of all items in the estimate, how the project will be executed, and how the work environment will lend itself to the project. The ROM estimate is obtained in the initiation phase of a project for the whole project with an accuracy range of -25 to $+75$ %.
- **Budget estimate**
  A budget estimate is the type used to approximate the cost of a project activity, project, or program for budgeting and planning purposes only. Not accurate enough to provide a basis for a firm commitment. The estimates are often based on design layouts, equipment details or Statement of Work (SoW) prepared by an external contractor. This type of estimate is derived during the planning phase for the whole project with an accuracy range of -10 to $+25$ %. In the resource industry, budget estimates are often prepared upon completion of the detailed design. Companies use these estimates internally to establish funds for the project prior to the release of a request for proposal (RFP). The 'S-Curve' shown in Fig. 15.15 is developed using budget estimate type of cost estimation.
- **Definitive or detailed estimate**
  A definitive estimate is based on detailed information from each work package within the WBS or estimates completed at the activity level. It is prepared from well-developed plans, and real quotes. Definitive estimates are prepared using bottom–up cost estimating method, which is discussed Sect. 16.4.2. The estimates are commonly developed after an RFP contract has been signed off. In project management, a definitive estimate is as good as it gets! There is always the

possibility of some variance from the estimate, but definitive estimates are -5 to $+10\,\%$ accurate.

The tools used for cost estimating include top–down, bottom–up, and parametric cost estimating methods. These methods are explained below in more detail.

16.4.1 Top–Down Cost Estimating Method

The top–down cost estimating method is also known as the *analogous estimating method*. It is used to determine rough order of magnitude (ROM) estimates in the initiation phase of the project. The method uses the actual durations, effort or costs from previous projects as a basis for estimating the effort or costs for the current project.

Analogous estimating uses a similar past project to estimate the duration or cost of the current project, thus the root of the word: analogy. It is used when there is limited information regarding a current project. An analogous cost estimate, just like top–down estimate, is generally not as accurate as other estimating techniques. It is considered a combination of historical information and expert judgment. For example, if it used to cost $100,000 to clear an environmental site a few months ago, other things being equal, it can be estimated that it will still cost same amount for clearing similar site, if it were to be done at present.

16.4.2 Bottom–Up Cost Estimating Method

This type of technique involves estimating the cost of the individual work packages and then summarising, or rolling up the individual estimates to reach the project total. The bottom–up method is considered to be the most accurate method for generating project estimates. It is used to determine budget or definitive estimates during the planning phase and at the start of each project stage. The method uses the work breakdown structure (WBS) developed during the planning stage of the project. Estimates are created for all tasks at the lowest level of the WBS and then these are accumulated to determine the estimates for the whole project (see Fig. 16.6). One disadvantage of the bottom–up method is that it is much more time-consuming than other methods.

16.4.3 Parametric Cost Estimating Method

The parametric method is also known as the *object-based* method. It is used to obtain definitive estimates and to confirm bottom up estimates where possible. Parametric

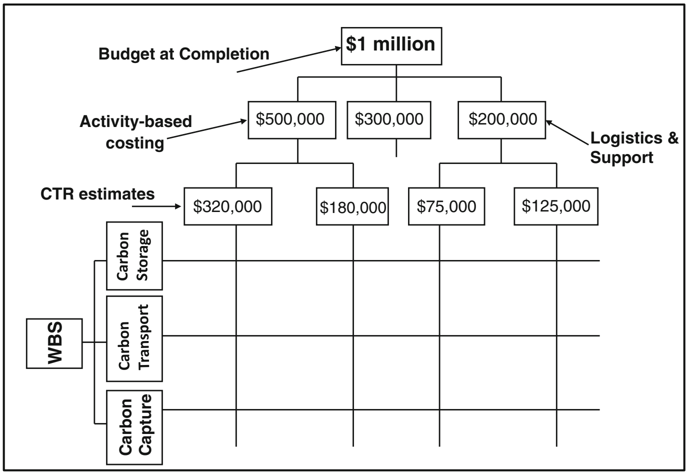


Fig. 16.6 An example of CBS/WBS matrix for CO_2 sequestration project, showing the task to be done and the cost of each task

estimating, a more accurate technique for estimating cost and duration, uses the relationship between variables to calculate the cost or duration. Essentially, a parametric estimate is determined by identifying the unit cost or duration and the number of units required for the project or activity. The measurement must be scalable in order to be accurate. A simple concept is used, namely: if the amount of effort needed to carry out a particular activity for a particular object is known, and the number of objects is known, the effort required to perform the activity for all the objects can be determined. The amount of effort for the single activity can be determined either from a standard, which has been established from previous experience, or by executing a sample activity if no standard exists.

For example, if it took two hours to clear a site of 1000 m^2 last week and this week and there is a requirement to clear four sites, it could be estimated that it will take eight hours to clear. However, if the first one hour was spent conducting an environmental impact assessment and preparing the risk assessment matrix, the estimate would need to be scaled appropriately: one hour for conducting an EIA and then seven hours to clear sites, for a total of eight hours.

16.4.4 Decomposition of the Cost Breakdown Structure (CBS)

A cost breakdown structure (CBS) is simply a hierarchical breakdown of a project into cost elements and organizing the latter in a structured fashion. Since you are familiar with the concept of a work breakdown structure (WBS), the CBS is very similar and can be used to develop project budget. As one of the cornerstones of project planning, the project budget must be coordinated with work packages defined in the WBS earlier. The WBS sets the stage for creating the project schedule; the CBS subsequently assigns the necessary resources to support that schedule. The ways in which cost data are collected and interpreted mainly depend upon whether the company employs a *top–down* or *bottom–up* budgeting approach.

The top–down budgeting requires the direct input from the organization's top management, while the bottom–up budgeting begins inductively from the cost breakdown structure to apply direct and indirect costs to project activities. The sum of the total costs associated with each activity are then aggregated first to the work package level, then at the deliverable level, at which point all task budgets are combined, and then higher up the chain where the sum of the work package budgets are aggregated to create the overall project budget. An example of a cost breakdown structure and its relationship with the WBS is shown in Fig. 16.6. Most project budgets use some form of activity-based costing (ABC), a budgeting method that assigns costs first to activities and then to the projects based on each project's use of resources.

16.5 Activity Scheduling Techniques

"I love deadlines. I like the whooshing sound they make as they fly by"—Douglas Adams (1952–2001).

In the late 1950s several techniques were developed to assist in the planning of complex projects. These include the critical path method (CPM) and program evaluation and review technique (PERT). CPM was developed in the late 1950s by Morgan Walker of E.I. Du Pont and James E Kelly of Remington Rand Univac Corporation and was first used to schedule maintenance shutdowns in chemical processing plants. PERT was developed by Booz, Allen and Hamilton in conjunction with the U.S. Navy in 1958 with the aim of coordinating the activities of more than 11,000 contractors who were working on the Polaris missile program (Burke 2001; Shtub et al. 2005; Dandy et al. 2007; Vanhoucke 2012). Both techniques represent all activities involved in a project as a network of arrows and nodes. Calculations can then be carried out to determine the information required to develop a network and the durations of all activities. The basic difference between the two techniques is that CPM assumes that the durations of all activities are deterministic, whereas PERT represents the durations of activities as random variables with optimistic, pessimistic and most likely estimates of their durations (Dandy et al. 2007). See Sect. 7.4.2.3 for more discussion on PERT.

Activity scheduling techniques lie at the heart of project planning and subsequent executing, monitoring and control processes. Activity scheduling represents the conversion of project goals and objectives into an achievable methodology for their completion. It creates a timetable and reveals the network logic that relates project activities to each other in a coherent fashion. Project management institute, in its PMBoK guide, defines activity schedule as "the planned dates for performing project activities and meeting project milestones" (PMI 2013). It employs various analytical techniques such as critical path method (CPM), arrow diagraming method (ADM), and precedence diagraming method (PDM) to calculate the early and late start and finish dates for the uncompleted portions of project activities.

16.5.1 Critical Path Method (CPM)

Critical path method (CPM) is a step-by-step activity scheduling technique for project planning that defines critical and non-critical tasks with the goal of preventing time-frame problems and process bottlenecks. It is a network analysis technique used to determine the amount of scheduling flexibility (the amount of float or slack) on various logical network paths in the project schedule network, and to determine the minimum total project duration. It involves the calculation of early and late start, early and late finish dates for each activity.

The basic feature of the technique is the construction of a logic diagram, or network, which represents the various tasks involved in the project and the way in which these tasks depend logically on each other. The construction of a network early in the planning phase allows a systematic analysis of what the project entails, a clarification of the assumptions on which the plan is based and an opportunity to examine alternative ways of achieving the project objective. Time-, cost-, and resource-requirement estimates are developed for each activity during the network-planning phase. The estimates may be based on historical records, time standards, forecasting, regression functions, or other quantitative models.

The two different types of notation that are commonly used for activity scheduling techniques are activity on node (AON) and activity on arrow (AOA) notation, which employ arrow diagramming method (ADM) and precedence diagramming method (PDM) respectively. The two methods are illustrated in the subsequent sections. Either notation may be used to represent the precedence relationships between activities.

16.5.1.1 Arrow Diagraming Method (ADM)

Arrow diagramming method (ADM) uses *activity-on-arrow* network approach to perform critical path analysis. This method uses numbered "nodes" that represent stages or events of project completion. The event nodes are connected with the arrows, which represent the constituent activities of a given project. The event nodes represent points in time when all activities leading into an event have been completed. Thus, activities that originate from a certain event cannot start until the activities that terminates at the same event have been completed.

In constructing the network, an arrow is used to represent an activity, with its head indicating the direction of progress of the project. The precedence relations among activities are introduced by numbered nodes which defines the events. To

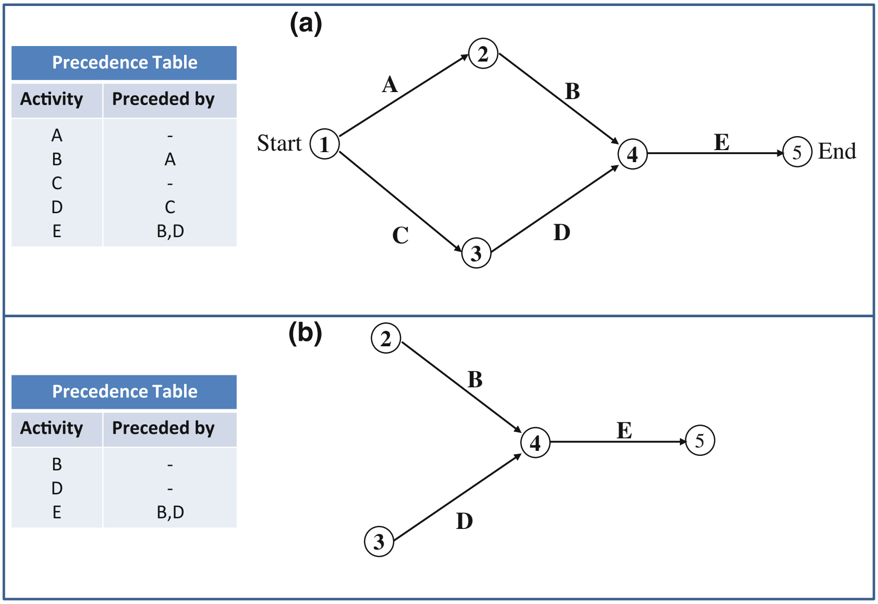


Fig. 16.7 Activity on arrow notation. **a** Activity on arrow network diagram. **b** Activity on arrow network diagram observing Rule No. 1

illustrate activity-on-arrow (AOA) notation, consider a simple project consisting of five activities: A, B, C, D and E. Suppose that Activity A must be completed before activity B can commence. Activity C must be completed before Activity D can commence; and Activities B and D must be completed before Activity E can commence. A precedence table and network diagram for this project using the arrow diagraming method is shown in Fig. 16.7a.

There are two basic rules that must be observed, while developing an AOA network diagram:

1. Where the starting node of an activity is also the finishing node of one or more other activities, it means that all the activities with this finishing node must be completed before the activity starting from that node can be commenced, (see Fig. 16.7b).
2. Each activity must have a different set of starting and finishing node numbers. This poses a problem when two activities start and finish at the same event node. This means Fig. 16.8a is not correct. In order to apply this rule, therefore, an artificial or "dummy" activity is inserted into the diagram to properly indicate all network logic (see Fig. 16.8b). Dummy activities are given zero duration so that the analysis is not affected.

Consider the following project for example:

- Activity B cannot start until Activity A is finished;

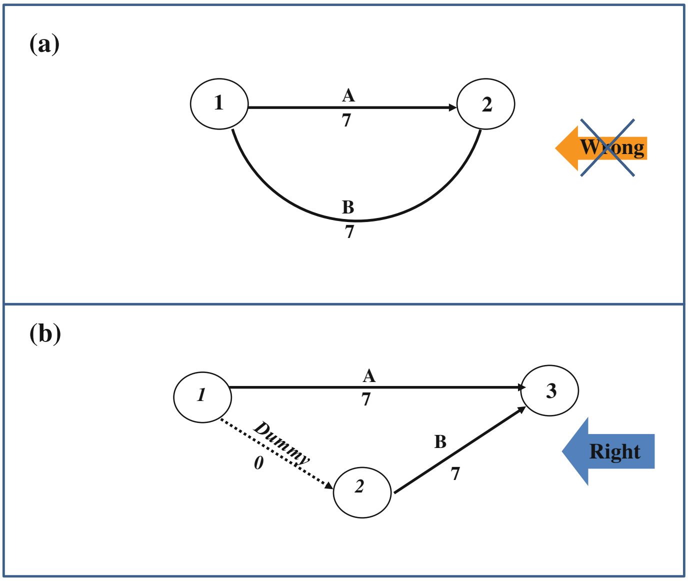


Fig. 16.8 Activity on arrow network diagram (**a**, **b**) observing rule No. 2: When two activities start and finish at the same event node, a dummy activity is inserted into the diagram to create a logic diagram

- Activity E cannot start until Activities B and D are finished;
- However, Activity D requires both Activities A and C to complete before it can commence. A suitable organisational network for this project is shown in Fig. 16.9. The activity between events 2 and 3 in Fig. 16.9 is an example of a *dummy* activity. Note that a dummy activity, D1 has been introduced to satisfy the precedence logic.

Over the past few years, popularity of the ADM has rapidly fallen due to its complexity and difficulty of use. The three major disadvantages of the ADM include the following:

Precedence Table	
Activity	Preceded by
A	-
B	A
C	-
D	A, C
E	B, D

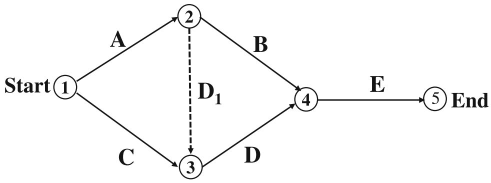


Fig. 16.9 Use of dummy activity (D_1) to illustrate a precedence logic of an AOA notation consisting of five activities: A, B, C, D, and E

1. The ADM permits only finish-to-start logical relationships. It is not possible to show lead and lag, except by adding or subtracting time, which makes project tracking difficult if not impossible.
2. Dummy activities must be inserted into the diagram to properly indicate all network logic. However, the network can only show dependency of one task on other, but not the duration or costs associated with it.
3. The ADM is no longer popular, compared to the precedence diagramming method, which is somewhat simpler to use and all project management software programs supports the precedence diagramming method.

16.5.1.2 Precedence Diagramming Method (PDM)

The precedence diagramming method (PDM) is an alternative method used to represent project activities and their interrelationships.

It uses *activity-on-node* network approach to perform critical path analysis. In the precedence diagramming method, the activity names are written in the diagram box called *node* and arrows are used simply to indicate how the activities are related or connected logically to one another. The method is most commonly used in the field of project management and readily available on project management software. Most project management practitioners find the PDM natural and easy to work with. The basic advantage of this method is that there is no need for *dummy* arrows and it is relatively easy to construct.

Figure 16.10 shows an organizational network for the same project under review, using activity on node (AON) notation. In this case each activity is represented by a box. There is also a box for the start and finish of the project. The precedence

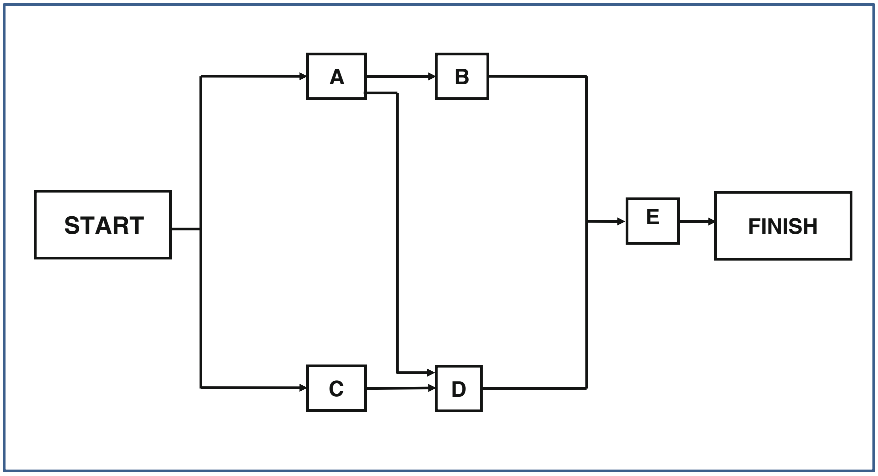


Fig. 16.10 Activity on node notation

relationship between activities is represented by arrows. From the information provided earlier, Activities A and C do not need any activities to be completed before they can start. Therefore, they can both commence at the beginning of the project as shown in Fig. 16.10. Activity A must be completed before Activity B can commence, so an arrow goes from A to B. Similarly Activity C must be completed before Activity D can start, so an arrow runs from C to D. However, Activity A and C must be completed before Activity D can start, so two arrows run through A and C to meet Activity D. Activity B and D must be completed before Activity E can start. Note the use of dummy activity in Fig. 16.9 as compared to the AON network in Fig. 16.10 without the use of dummy activity.

As both B and D must be completed before Activity E commence, they both have arrows running into Activity E. Finally the project can end once Activity E is finished.

16.5.2 Critical Path Terminology

In Sect. 16.3, under the title *scope planning techniques*, it was mentioned that every activity in the WBS is given a unique identification number called the WBS code. These codes are required for computer processing and can range from small serial numbers to complex alphanumeric codes containing 10 or even more characters (depending on the size and complexity of the networks and projects being planned). Same code can be applied in developing the critical path network to represent project activities as illustrated in Fig. 16.11.

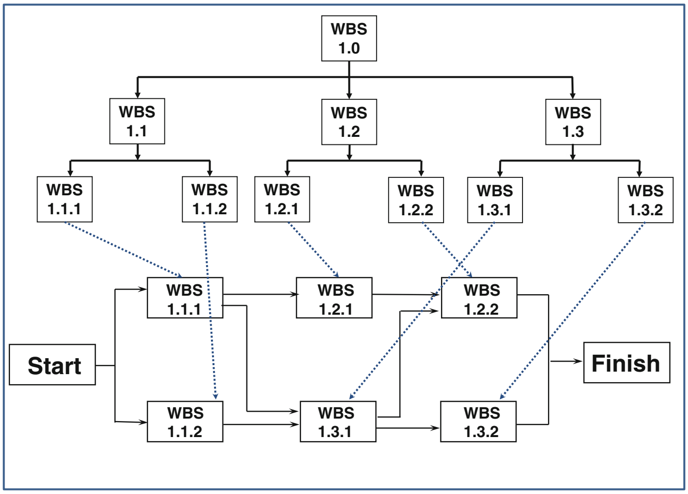


Fig. 16.11 Relationship of WBS to AON network diagram

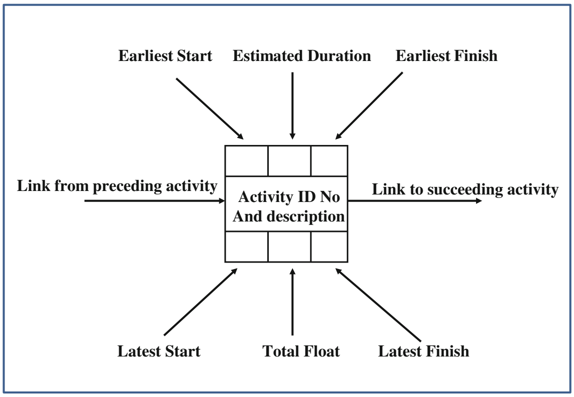


Fig. 16.12 Activity symbol used for forward and backward pass computations in activity-on-node (AON) network diagram

There is a standard notation for performing critical path calculations. The number of terms associated with the activity symbol for the standard notation shown in Fig. 16.12 are defined below:

- **Activity Identifier Number**: The unique identification number for each activity, derived from the WBS.
- **Earliest Start (ES)**: The earliest date by which an activity can start assuming all the preceding activities are completed as planned.
- **Estimated Duration (ED)**: The most likely (or PERT) duration estimate for completing an activity.
- **Earliest Finish (EF)**: The earliest date by which an activity can be completed assuming all the preceding activities are completed as planned.
- **Latest Start (LS)**: The latest date an activity can start to meet the planned completion date.
- **Latest Finish (LF)**: The latest date an activity can finish to meet the planned completion date.
- **Activity Float (AF)**: A measure of flexibility, or inherent surplus time in an activity scheduling. It is also called *slack*. Activity float indicates how many working days an activity can be delayed or extended before it can affect the completion date of the project or any target finish dates (milestone). Note that where an activity has zero float, this indicates the activity is on the *critical path*.

Float is calculated by either of the two equations:

$$Float = LS - ES \tag{16.1}$$

or

$$Float = LF - EF. \tag{16.2}$$

16.5.3 Logic Rules, Sequences and Dependencies

The first step in the preparation of a network is to produce the logic diagram for the project. This defines the sequence in which jobs or activities must be completed and takes into account all the restraints on the completion of the project.

The steps in the preparation of a logic diagram include the following (see Fig. 16.11);

- list all the activities (or work packages) that make up the project,
- prepare a draft network following the logic rules,
- test the logic of the completed draft, using the dependencies, and
- draw the final network.

List the Activities

A list is prepared of all the activities that make up the project. These activities will be determined in conjunction with the project management staff. The main part of this step will be defining the size and scope of each activity and who will be responsible for each activity.

Preparation of a Draft Network

A draft network is prepared from the list of activities following the logic rules. The logic is built up in consultation with the project staff, taking into account only the internal constraints of the project. No account will be taken at this stage of the constraints placed on the sequence of activities that may be imposed by factors such as the availability of time, budget or human resources.

Sequence Activities

Sequencing is about identifying dependencies between activities. This means putting activities into a specific order by determining an activity's immediate prerequisite activities, called *predecessors*, and leaving no loose ends.

A portion of the dependencies will be arranged in pure "technological order". These are termed hard or logical dependencies, meaning that the technology of work mandates such sequence. An example is an environmental engineer must perform a groundwater and geoprobe soil analysis before well installation; the other way around is not possible. Disregarding hard dependencies may lead to rework and project delay. But not all dependencies are hard; some of them are soft or preferential ones. They are not required by the work logic but set by choice, reflecting one's experience and preferences in scheduling. Dependencies may also be dictated by availability of key resources. If two activities require the same resources, one will have to follow the other. Once the dependencies are established, they can be recorded as was done in Figs. 16.9 and 16.10.

Understandably, some dependencies will be hard or logical; others will be soft or preferential. Both types can be used to create overlapping activities for the purpose of *fast-tracking* the activity scheduling. For example, instead of performing value assessment review (VAR) and then making the final investment decision (FID), it may be more efficient to overlap the two activities by performing the VAR and make a decision the same day.

Activity Dependency

A dependency is simply a relationship that exists between pairs of activities. To say that activity B depends on activity A means that activity A produces a deliverable that is needed in order to do the work associated with activity B. There are four primary types of network dependency or logical relationships as presented in Fig. 16.13. These are discussed below.

1. **Finish to Start**: When activity A finishes, Activity B may start.
2. **Start to Start**: Essentially, both activities or tasks starts at the same time, especially when the time *lag* shows zero. Start to Start lags are becoming increasingly used as a means to accelerate projects through a schedule compression technique known as *fast-tracking*. We will discuss this in more detail in Sect. 16.6.2.
3. **Finish to Finish**: Activity A must finish before Activity B can finish.
4. **Start to Finish**: Activity A must start before activity B can finish.

In practice, the simple *finish-to-start* logic connector is almost always used. The other types of logic connectors are seldom used for various reasons.

Precedence Diagramming with Lead–Lag Relationships

Additional constraints can be placed on any of the four logical relationships (connectors) described above. These constraints are used primarily to create *leads* and *lags* in activity sequencing. A lead relationship is one where it is necessary for the predecessor activity to have achieved a certain percentage of completion before the

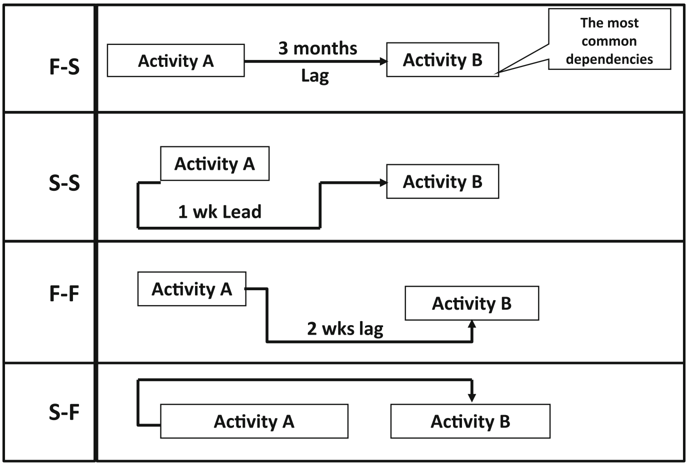


Fig. 16.13 Constraint options in precedence network notation showing the difference between lead and lag dependencies

successor task can start. A lag relationship occurs when it is necessary for the predecessor activity to have been completed for a set period of time before beginning the successor task. Simply put, accelerating a logic relationship is known as *leads*, while slowing it down is known as *lags*.

An example of a lead relationship in an environmental impact assessment (EIA) would be the case where scoping and baseline studies (i.e., the predecessor activity) may proceed for five days prior to the initiation of impact prediction and evaluation (i.e., the successor activity). The five-day lead could represent the time required to collect necessary information and data for performing impact prediction analysis.

An example of a lag relationship in an EIA situation is the case where it is cost-effective and less risky to wait two weeks after completing a new carbon capture and storage (CCS) facility (i.e., the predecessor activity) prior to connecting the pipelines (i.e., the successor activity). Figure 16.13 presents examples of lead and lag relationship between two activities.

16.5.4 Activity Duration and Timing

Activity durations are obtained in exactly the same way as with conventional networks. When they have been obtained, the network can be analysed. The principles of calculation are the same as with arrow diagrams, but, as there are no events, activity start and finish times are calculated directly. The start dates indicate the beginning of the time interval (e.g. January, if monthly) and the finish dates the end of the time interval (e.g. December).

There are four steps in the calculations of activity duration and timing;

1. calculate activity earliest start times (forward pass computation),
2. calculate activity latest finish times (backward pass computation),
3. calculate activity float, and
4. determine the critical path.

16.5.5 Critical Path Calculations

The critical path method embodies two basic sets of computations called the *forward pass computation* and *backward pass computation* to calculate activity *float* and determine the critical path.

16.5.5.1 Forward Pass Computation

The forward pass computation is performed by moving through the network from left to right (from start node to finish node), hence the name forward pass. The computation is carried out first to determine the earliest start and finish dates for each activity. The earliest start (ES) time for an activity is the earliest time at which all of its predecessor activities have been completed and the subject activity can begin. Using the calendar date, the earliest time of an activity with no predecessor activities is arbitrarily set to 1, that is, the first day on which the project is open for work. The ES time of activities having two or more predecessor activities is determined from the latest of the earliest finish (EF) times of the predecessor activities.

The earliest finish (EF) of an activity is calculated as follows:

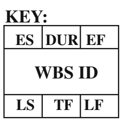
$$EF = (ES + Duration) - 1 \tag{16.3}$$

The reason for subtracting one time unit as shown in the equation above is to account for the fact that an activity starts at the beginning of a time unit (hour, day, week, month, year) and finishes at the end of the time unit. In other words, a one-day activity, starting at the beginning of a day, begins and ends on the same day.

For example, take a look at Activity B in Fig. 16.14. The earliest start (ES) is day 2 and the earliest finish (EF) is day 4. The duration is 3 days. Inserting numbers into the equation, the earliest finish (EF) for activity B is:

$$EF(B) = (2 + 3) - 1 = 4 \tag{16.4}$$

Note also that activity E has only one predecessor, which is activity C. The EF for activity C is the end of day 3. Because it is the only one predecessor of activity E,



WBS ID	Earliest Start (ES)		Duration of Preceding activity		Earliest Finish (ES + Duration – 1)
A	1	+	1	=	1
B	2	+	3	=	4
C	2	+	2	=	3
D	5	+	5	=	9
E	4	+	2	=	5
F	10	+	3	=	12

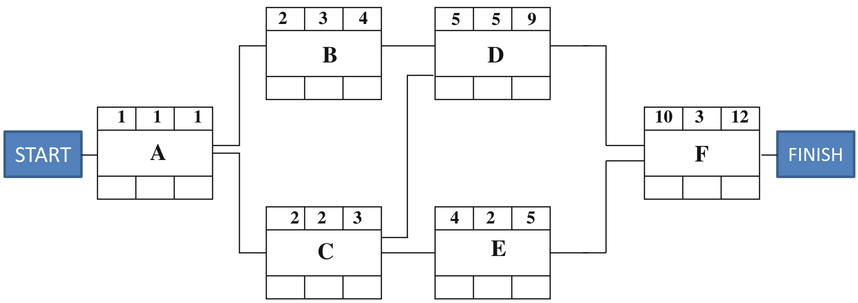


Fig. 16.14 Forward pass calculations, using ES and EF dates

the ES of activity E is the beginning of day 4. On the other hand, activity D has two predecessors, that is, activities B and C. When there are two or more predecessors, the ES of the successor, activity D in this cases, is calculated based on the maximum of the EF dates of the predecessor activities.

The EF dates of the predecessors, i.e., Activity B and C, are the end of day 4 and the end of day 3 respectively. The maximum of these is 4, and therefore, the ES of activity D is the morning of day 5. The resulting network is shown in Fig. 16.14.

16.5.5.2 Backward Pass Computation

Backward pass computation is carried out to determine the latest finish (LF) and latest start (LS) dates for each project activity. The latest start (LS) and latest finish (LF) times of an activity are the latest times at which the activity can start or finish without causing a delay in the completion of the project. The window of time between the ES and LS (or EF and LF) of an activity is the window within which the resource for work must be scheduled or the project completion date can be delayed.

To calculate these times, the network diagram is worked backward. First, the LF time of the last activity on the network is set to its calculated EF time.

The latest start (LS) of an activity is then calculated as follows:

$$LS = (LF - D) + 1. \tag{16.5}$$

In the example shown in Figs. 16.14 and 16.15, the LS for activity F is calculated as follows:

$$LS = (12 - 3) + 1 = 10 \tag{16.6}$$

Note, the +1 is required because the start and finish times are included in the duration of the activity.

The LF time of all immediate predecessor activities is determined by the minimum of the LS of the immediate successor activities, minus one time unit. For example, the LF date for activity B will be the end of day 4. On the other hand, consider activity C. It has two successor activities, activity D and activity E. The LS dates for them are 5 and 8, respectively. The minimum of those dates, day 5, is used to calculate the LF time of activity C, namely the end of day 4. The remainder of the calculation is shown in Fig. 16.15.

16.5.5.3 Calculating Activity Float

The float of an activity is defined as the amount of time for which an activity may be delayed from its earliest start (ES) without delaying the completion time of the project or any target finished dates (milestones). Also called *slack*, *total float*, or *path float*.

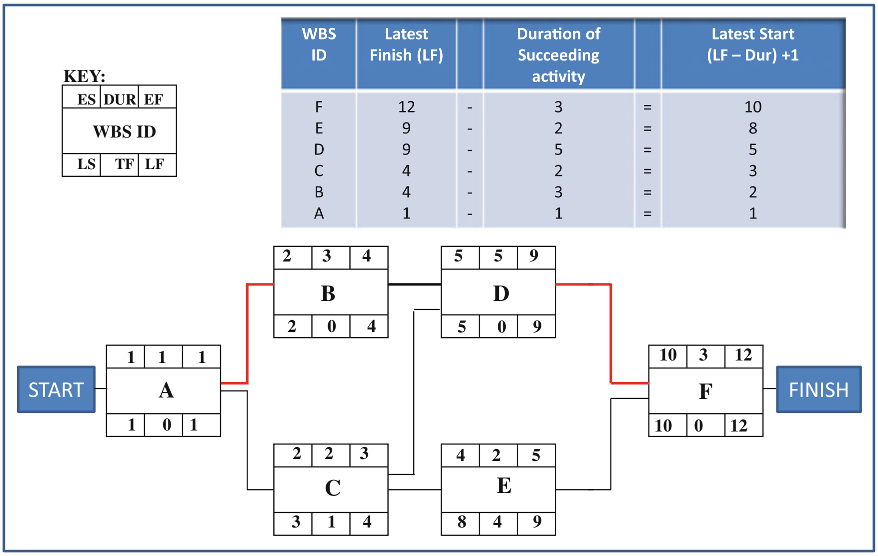


Fig. 16.15 Backward pass calculations, using LS and LF dates

Table 16.1 Calculating activity float

WBS ID	Earliest start (ES)		Latest start (LS)		Total float
A	1	−	1	=	0
B	2	−	2	=	0
C	2	−	3	=	1
D	5	−	5	=	0
E	4	−	8	=	4
F	10	−	10	=	0

Activity float is calculated by subtracting the activity duration from the calendar time allowed for the activity, that is, the difference between the latest start date and the earliest start date (LS − ES) or between the latest finish date and earliest finish date (LF − EF). For the example shown in Fig. 16.15, the calculation is shown in Table 16.1.

Always clarify whether a unit number refers to the start of the day, week or month. The use of calendar dates on documents will avoid confusion.

Float on Non-critical Activities

It is possible to calculate three kinds of float:

- **Total Float**
  Total float is the amount of time for which an activity may be delayed or its duration extended before it becomes critical. Using up total float on one activity may affect

Table 16.2 Calculating float on non-critical activities

WBS ID	Duration	Start events		Finish events		FLOAT		
		ES	EF	LS	LF	Total	Free	Independent
A	1	1	1	1	1	0	0	0
B	3	2	4	2	4	0	0	0
C	2	2	3	3	4	1	0	−1
D	5	5	9	5	9	0	0	0
E	2	4	5	8	9	4	0	−4
F	3	10	12	10	12	0	0	0

the total float on other preceding or succeeding activities. Thus, total float is the measure that is used to determine the critical activities in a project network.

- **Free Float**
  Free float is the amount of time for which an activity may be delayed without affecting the float on succeeding activity. Activity free float is calculated as the difference between the minimum ES of the activity's successors and the EF of the activity.
- **Independent Float**
  Independent float is the amount of float that an activity will always have regardless of the completion times of its predecessors or the starting times of its successors. Independent float takes a pessimistic view of the situation of an activity. It is useful for conservative planning purposes, but rarely used in practice.

For illustration, consider an activity with start and finish dates whose estimated duration (ED) is as shown in Fig. 16.12:

- Total float (TF) = [LF − (ES + ED)] + 1
- Free float (FF) = [EF − (ES + ED)] + 1
- Independent float (IF) = [EF − (LS + ED)] + 1.

The floats associated with the activities in Fig. 16.15 are calculated in Table 16.2. Thus the critical activities A, B, D and F have no float.

16.5.5.4 Determine the Critical Path

The critical path is defined as the path with the least float (slack) in the network diagram (Taylor 2008). This comes about when the end date of a project has been set in advance by the management. Otherwise, ***the path with zero float is generally referred to as the critical path***. All the activities on the critical path are said to be *critical activities*. These activities can create bottlenecks in the network if they are delayed. The critical path is also the longest path in the network diagram. In some networks, particularly large ones, it is possible to have multiple critical paths. If there is a large number of a path in the network, it may be very difficult to identify visually all the critical paths. For example, the critical path for network diagram shown in Fig. 16.15 is A–B–D–F. This is because this path has zero float.

After the network has been completed by going through the steps mentioned above, the completed network should be reviewed by the project management team. They will determine whether the completion date (or any intermediate dates) is acceptable.

If any of the dates are not acceptable, the programme will have to be shortened. This is done by shortening the critical path (e.g., by changing the logic, or reducing activity durations) using the schedule compression techniques, which will be discussed in Sect. 16.6.

16.5.6 Pros and Cons of Critical Path Method

Critical path method offers the following advantages:

- Graphic appeal. CPM is easily explainable, even to the laypeople, by means of the project network diagram that clearly charts the technological order of work. Data calculations are not difficult and can be handled readily and quickly by personal computers.
- Intuitive logic. In a simple and direct way, it displays the dependencies in the complex of activities comprising a project. The logic reveals which activities have to be executed before others can proceed.
- Focus on top priority. It pinpoints attention on the small group of activities that are critical to project completion time. This focus greatly adds to higher accuracy and, later, precision of schedule control.

Shortcomings of CPM include the following:

- It looks convoluted and perplexing to first-time users. The multitude of activities flowing into and branching out of the web of interrelated paths creates a sense of disorientation and complexity that is difficult to comprehend. As such one user puts it: "When I used it for the first time, CPM appeared to me as mind-boggling crow tracks, almost impossible to decipher".
- It is timeless, since it is a diagram without a timescale. Certainly, the diagram is accompanied by a tabular report of schedule dates, but for today's project managers pressed for time, speed, and efficiency, the inability to quickly read dates and float off the CPM Diagram is frustrating.
- It appears overwhelming when it comes to maintaining it for a very dynamic project, where frequent changes are the order of the day. Consequently, updating and changing the schedule may be very time-consuming.

16.6 Schedule Compression Techniques

Schedule compression refers to reducing the length of a project network. Two techniques are commonly used to compress a schedule. The first is called *crashing* the schedule, while the second is called *fast tracking*.

16.6.1 Crashing the Schedule

Crashing is done as a trade-off between shorter task duration and higher task cost. It should be determined a priori if the total cost savings realised from reducing the project duration is enough to justify the higher costs associated with individual task durations.

Activity durations may be reduced in the following ways;

- increasing crew numbers and sizes,
- increasing the amount of mechanisation,
- working overtime,
- increasing the number of shifts, and
- changing suppliers when delivery times are critical.

In all cases, the revised network should be redrawn and calculated to ensure that the new completion dates are acceptable.

16.6.2 Fast-Tracking the Schedule

Fast tracking is a schedule compression technique used to move one or more of the critical path activities from sequential to parallel (concurrent) relationships. The technique requires some sort of creativity from the project team in looking for ways to rearrange the project schedule without disturbing the logical relationship between activities in the network.

For example, in a simple treatment of contaminated site, it may be possible to begin with a screening process and feasibility study to ensure that the most cost-effective process combinations are selected while the methods of dealing with contaminants in the environment are still being considered. That is, decision to deal with the contaminants via removal, extraction, destruction or isolation method will not be affected by the decision to treat the contaminated site, and the net effect will be to shorten the project duration.

Major advantage of fast tracking include meeting customer requirements to shorten the project schedule. However, project can face increased risks and repetition of some of the project activities if not planned well. The main idea of fast tracking is to decrease project schedule in the network without sacrificing scope and quality. Remember the triple constraint concept.

16.7 Resource Scheduling Techniques

A project requires resources to execute the planned activities (or work packages). These resources include the labor, equipment, and materials required to get the work done. Labor is the people, such as craft, engineers, programmers, systems analysts, etc. Equipment includes such things as cranes, test rigs, process simulators, etc. Materials includes such things as the concrete to be poured, the wire to be installed, etc.

Besides, the activity scheduling techniques discussed earlier (e.g., critical path method (CPM), arrow diagramming method (ADM), precedence diagramming method (PDM) and schedule compression techniques) have proven to be helpful only when the project deadline is not fixed and the resources are not constrained by either availability or time. Since this is not practical even for small-sized projects, several techniques have been used to modify CPM results in account of practical considerations. The two main techniques used for this purpose are resource allocation and resource levelling heuristics.

16.7.1 Resource Allocation

Resource allocation, sometimes referred to as *resource loading*, attempts to reschedule the project tasks so that a limited number of resources can be efficiently utilized while keeping the unavoidable extension of the project to a minimum.

For illustration, consider a project network that has been scheduled to meet a required completion date, and all activities are planned at their earliest possible starting dates. As demonstrated in Table 16.3, if all activities were to start at there earliest start times then the number of resources required varied considerably over the duration of the project at any time ranged between one and six.

By assigning the number of resource units to each activity, the total resources loading can be established (see Fig. 16.16).

Table 16.3 Resource table showing the number of resources required per day

WBS ID	Duration	Start events		Finish events		FLOAT			Resource needed per day
		ES	EF	LS	LF	Total	Free	Independent	
A	1	1	1	1	1	0	0	0	2
B	3	2	4	2	4	0	0	0	6
C	2	2	3	3	4	1	0	−1	2
D	5	5	9	5	9	0	0	0	3
E	2	4	5	8	9	4	0	−4	1
F	3	10	12	10	12	0	0	0	2

WBS ID	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	2											
B		6	6	6								
C		2	2									
D					3	3	3	3	3			
E				1	1							
F										2	2	2
TOTAL	**2**	**8**	**8**	**7**	**4**	**3**	**3**	**3**	**3**	**2**	**2**	**2**

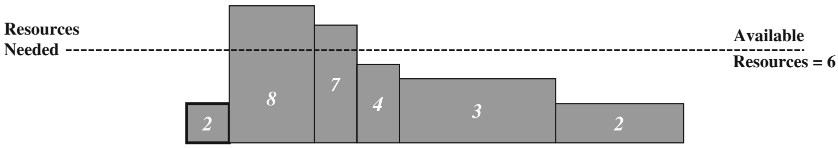


Fig. 16.16 Early start Gantt chart with resource loading histogram

The figures shown on the activity bars are the number of unit of resources needed by the activity. By summing these numbers we arrive at the total resources required per day. The initial resource requirement during the different time periods of the project may also be represented in form of a histogram, as shown in Fig. 16.16.

One now wishes to level the resource requirements, ideally obtaining a horizontal straight line of usage over the project duration. The technique used for such purpose is the resource levelling heuristics.

16.7.2 Resource Levelling Heuristics

In almost every project, there is always some point during the life of the project when the number of resources required is greater than the resources available. A technique called resource leveling heuristics is used to alleviate the problem, if not eliminate it completely.

The PMBoK Guide defines resource leveling as a schedule network analysis technique applied to a schedule that has already been analyzed by the critical path method (CPM). It is used to optimize the distribution of work among resources (PMI 2013).

Resource leveling, often referred to as *resource smoothing*, attempts to reduce the sharp variations among the peaks and valleys in the resource demand histogram (as shown in Fig. 16.16) while maintaining the original project duration.

WBS ID	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	2											
B		6	6	6								
C						2	2					
D					3	3	3	3	3			
E								1	1			
F										2	2	2
TOTAL	**2**	**6**	**6**	**6**	**3**	**5**	**5**	**4**	**4**	**2**	**2**	**2**

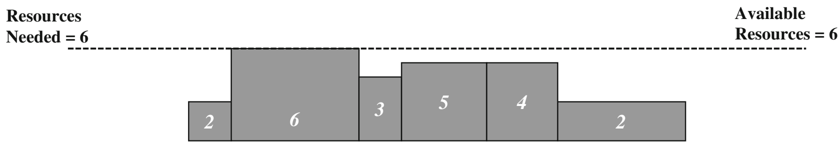


Fig. 16.17 Early start modified Gantt chart with resource levelling histogram

The number in each box represent number of resources required per day. If the maximum number of resources available to this project per day was 8, no adjustments to the resource loading would be required. However, if there was a premium on a smooth resource profile with time, or if there was a maximum of say 6 resources per day available, use could be made of the four days float of activity E. By shifting activity E from its early start of day 4 to its late start of day 8, the resource loading would be reduced to a maximum of 6 (see Fig. 16.17).

Resource leveling heuristics involves using the float or *slack* in the project schedule to allow certain activities to be performed later than planned, thereby permitting a smoother buildup of resources. Of course, this may not always work as there may not be enough float to move the tasks around in order to achieve the desired results, but certainly worth the effort. Note that whenever float is used to level resources, the risk of critical project delays increases. In this case, seeking an advantage in resource optimization creates a disadvantage in time management.

16.8 Concluding Remarks

In this chapter, we examine six project management techniques: Delphi, scope planning, cost estimating, activity scheduling, schedule compression and resource scheduling techniques. The techniques are useful for managing environmental project requirements. The techniques are also useful in planning the project scope, cost, time, risk, and resources to ensure success in terms of delivering on time, on target and within budget.

Project management clothes itself in precise techniques which are, in realty, founded upon intuition, judgement and experience—the crucial skills that most management schools fail to teach. Indeed, the more the much-vaunted techniques of project management are examined, the more they become revealed as tools which, no matter how useful, are founded on the employment of judgement.

Techniques are about the ideas and concepts, which underlie them. Environmental project managers hoping to use them as some form of life-belt will be sorely disillusioned. And yet, ironically, if they would only ask about what is beneath the surface, they might find much of interest. Only in this way can project management techniques discussed in this chapter be appropriated and usefully employed.

References

Burke R (2001) Project management. Planning and control techniques, 3rd edn. Wiley, New York

Dandy G, Walker D, Daniell T, Warner R (2007) Planning and design of engineering systems, 2nd edn. CRC Press, Boca Raton

Dunham R (1998) The Delphi technique. University of Wilsconsin, School of Business. www.instruction.bus.wisc.edu/obdemo/readings/dephi.htm

Havranek TJ (1999) Modern project management techniques for the environmental remediation industry. CRC Press, Boca Raton, 456p

Kerzner H (1984) Project management: a systems approach to planning, scheduling and controling, 2nd edn. Van Nostrand Reinhold, New York

Linstone HA, Turoff M (1975) The delphi method: techniques and applications. Addison-Wesley Pub. Co., Advanced Book Program, 620p

Meredith JR, Mantel JS (1999) Project management: a managerial approach, 4th edn. Wiley, New York

Miller M (2009) Building a project work breakdown structure (p 193). CRC Press, Boca Raton

PMI (2013) A guide to the project management body of knowledge (PMBOK guide), 5th edn. Project Management Institute, Newtown Square

Shtub A, Bard JF, Globerson S (2005) Project management. Processes, methodologies and economics. Pearson Education Inc., Upper Slade River

Taylor JC (2008) Project scheduling and cost control: planning, monitoring and controlling the baseline. J. Ross Publishing Inc, Plantation

Vaidyanathan G (2013) Project management: process, technology, and practice. Pearson, Upper Saddle River

Vanhoucke M (2012) Project management with dynamic scheduling: baseline scheduling, risk analysis and project control, vol XVIII. Springer, New York

Chapter 17
Implementing Environmental Project Management

> *For any project to be successful, project strategy, project leadership, project management, and good communications are essential*
>
> —The authors

There has been a noticeable paradigm shift from the fundamental idea that business has to make an economic profit to survive to include the so called "double bottom line", where businesses showed concern for the profitability of their investments and contributing to community development. Now the "triple bottom line", otherwise known as the "win–win–win" concept, a framework developed by John Elkington in 1994, is being considered by many authors (e.g., Hansen 1995; Lipow 2012; Henriques and Richardson 2013; Martinez 2015; Awange 2012; Awange and Kiema 2013) as the best method for measuring project's sustainability performance.

It is evident from the preceding chapters that project management, environmental management and spatial methods can significantly improve environmental project performance, in terms of lower cost and shorter duration, while at the same time assessing the impacts of project activities on the environment and ecosystems. These improvements go a long way toward serving the interests of project sponsors, government and the public in general. In addition, the improved performance gained by the implementation of environmental project management methods and processes also serves the interest of environmental protection/remediation companies. The efficiencies achieved through the implementation of environmental project management techniques allow increased profit margins, improved social justice and reduced pollution costs.

With the benefits of environmental project management principles understood, the pertinent question to ask is: "How do we determine the critical success factors for effective environmental project management?" It must be understood that without proper identification of the critical success/failure factors at the initiation phase of the project life cycle, it will be impossible for the project manager to make full use of the environmental project management methods or for the project organisation to realise the huge benefits of these methods. This chapter discusses the critical success factors necessary for successful delivery of environmental projects both in the

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developed and developing countries. As the revenues from economic and social benefits of the effective environmental management become eroded by increased carbon tax/compliance liabilities, resource companies and operators can no longer afford the inept "business as usual" philosophy to maintain their status quo. Hence, smarter ways of managing nature and the environment without reducing profit, increasing cost, and extending project completion time are required more than before in order to maintain a competitive edge as well as a favourable bottom line (see, e.g., Elkington and Burke 1987, Zeemering 2014). It is imperative that resource companies embrace environmental project management methods discussed in this book in order to deploy available resources, time, and budget in ways that maximize the overall project outcome and deliver maximum returns to all stakeholders (project sponsor, government, and general public).

17.1 Critical Success/Failure Factors

The main challenge of environmental project management lies in achieving all of the project goals and objectives, while utilizing the resources allocated and adhering to classic project constraints of scope, quality, cost and time. Organisations in the environmental protection and remediation industry must confront these challenges in order to ensure the success of projects undertaken.

It is generally accepted that the success or otherwise of a project can be defined through the convergence of, and the ability of the process to meet the technical goals of the project, whilst not deviating from the three constraints of quality, time and cost; the usefulness of the project as perceived by beneficiaries and sponsors as well as the project team; and the performance of the project (Kerzner 2003). By such definition, project success or failure can only be effectively measured at the completion of the project. Baccarini (1999) concurs with Kerzner's definition of project success by defining success or failure as the elements of the project log-frame and thus, the effective utilisation of the project output.

Projects generally fail as a result of poor planning, constant changes in the scope, deadline, and budget. Boyd (2001) introduced five maxims of measuring project satisfaction regardless of project scope, size, or duration which are;

1. delivering the product that the customer desires or needs,
2. delivering quality consistent with price,
3. delivering project within the timeframe stipulated by the customer,
4. delivering the desired degree of feedback that the customer desires, and
5. having a system of conflict resolution that is fair to both the customer and the development team.

Generally, critical success factors are a set of project variables or factors that are strongly correlated to project success, and whose maximisation or minimisation, depending on whether they are favourable or unfavourable, will lead to project success. According to Rockart (1981), critical success factors are the limited number of areas in which satisfactory results will ensure successful competitive performance for the individual, department, or organisation. They are the few key areas where things must go right for the business to flourish. If results in these areas are not adequate, the organisation's efforts for the period will be less than desired.

17.2 Planning, Monitoring and Control System

To maintain a competitive edge as well as a favourable bottom line, some proactive organisations have found it necessary to develop a project planning, monitoring and control system, which fully supports their project phase activities. A typical project planning and control system includes the project planning and control processes, the knowledge areas, tools and techniques used to achieve project deliverables. In practice, the environmental project life cycle shown in Fig. 3.14 can be used as a standardized process to facilitate planning, monitoring and controlling activities of any environmental project. This is referred in PMBoK Guide as the planning and controlling functions of project management (PMI 2013). As shown in Fig. 17.1, the boxes on the upper half of the figure represent the organizing, planning and scheduling functions, while the boxes on the lower half represent monitoring and controlling functions. The process represents the overall methods and procedures by which environmental projects are planned and controlled.

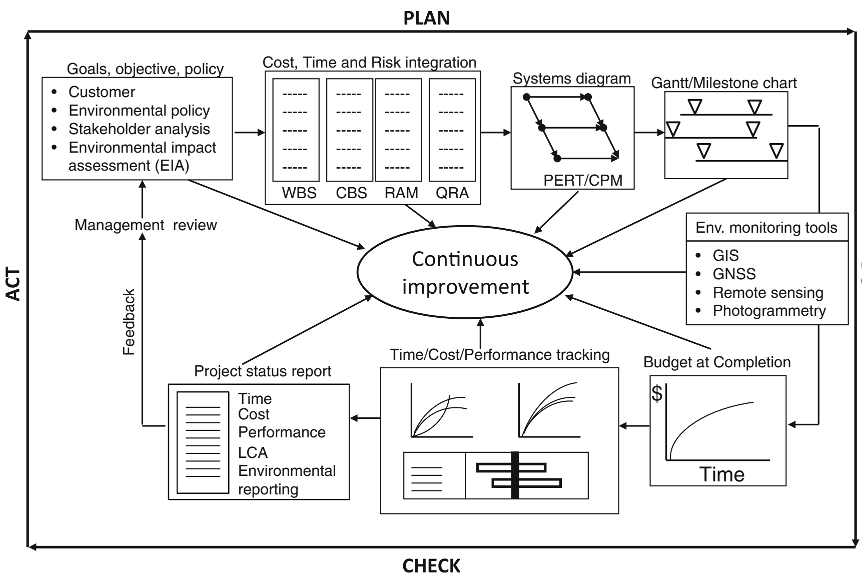

Fig. 17.1 The environmental project planning, monitoring and control system (Adapted from Kerzner, H., Project Management: A Systems Approach to Planning, Scheduling and Controlling, 3rd ed., Van Nostrand Reinhold, New York, 1984, p. 577)

The environmental project management and monitoring tools identified in Fig. 17.1 (e.g., stakeholder analysis, CPM systems diagram, earned value analysis, EIA, GIS, GNSS and photogrammetry) have been exclusively discussed in part III. Also in part III, environmental project management techniques such as decomposition of the work breakdown structure (WBS), program evaluation and review technique (PERT), and multi-criteria decision analysis (MCDA) were also discussed.

17.3 Education and Training

Research has shown that there is an acute shortage of trained technical experts and professionals in the area of environmental project management. In fact, there is no such body as “Environmental Project Management Institute” or “Society of Environmental Project Management Professionals”. Education and training programs are necessary to address this shortage by cultivating professionals trained in the area of environmental project planning, risk assessment, monitoring of environmental pollution and restoration of contaminated sites, using the environmental project management tools and techniques discussed in this book. The programs should be organized into three levels for undergraduate, graduate and Masters. However, the EnvPM education and learning should take cognizant of the fact that EnvPM is a much broader discipline than simply collection of tools and techniques. Hence, more emphasis should be placed upon concepts, methods and processes for solving the problem of greenhouse gas emissions, climate change, industrial waste and degradation of biodiversity.

In addition, short courses and workshops should be provided for industry professionals to build their knowledge of new methods in environmental project planning, monitoring and control. This can be done in collaboration with other peak bodies in the environmental protection, contamination and remediation industry. The training courses should be designed to meet industry needs for information, provide an enhanced skill base and increase awareness of enviro-technologies, modern environmental project management methodology and applications.

17.4 Concluding Remarks

This chapter discusses environmental project planning, monitoring and control system, using the PMBoK, and plan-do-check-act (PDCA) methodology. Project management study involves the three systematic steps of planning, scheduling, evaluating project performance, which is required for achieving the desired results on time and within budget. Planning involves breaking the project into smaller activities and estimating their times and costs and allocating responsibilities of the project implementing team. Scheduling involves identifying sequential relations between activities, sequencing them and estimating the project completion time. Project performance evaluation starts with implementation; and time, costs and quality (i.e., the triple constraints) are checked to ensure conformance to plans.

It should be noted that planning environmental protection/remediation project is typically done at the proposal stage under tight time constraints. The proposal submitted often represents the environmental project management plan. Because of the tight time constraints, there can be a tendency to pull a proposal together quickly and not worry about planning until the project is awarded. This is a quick recipe for project failure.

The education and training program, proposed in this chapter, was designed to provide readers with an application-based knowledge of environmental project management principles, method, and processes. At the completion of the training program, participants should be able to apply the knowledge acquired to project-related tasks in the field of environmental contamination and remediation science.

References

Awange JL (2012) Environmental monitoring using GNSS, global navigation satellite system. Springer, Berlin

Awange JL, Kiema JBK (2013) Environmental geoinformatics monitoring and management. Springer, Berlin

Baccarini D (1999) The logical framework method for defining project success. Proj Manag J 30(4):25–31

Boyd A (2001) The five maxims of project satisfaction. Aslib Proceedings 53(10): 423–430

Elkington J (1994) Towards the sustainable corporation: win-win-win business strategies for sustainable development. Calif Manag Rev 36(2):90–100

Elkington J, Burke T (1987) The green capitalists: how to make money—and protect the environment. Victor Gollanez, London

Hansen JL (1995) Invisible patterns: ecology and wisdom in business and profit. Greenwood Publishing Group, Westport, p 206

Henriques A, Richardson J (2013) The triple bottom line: does it all add up. Earthscan publishing, London

Kerzner H (1984) Project management: a systems approach to planning, scheduling and controling, 2nd edn. Van Nostrand Reinhold, New York

Kerzner H (2003) Project management: a systems approach to planning, scheduling and controlling. Wiley, New Jersey

Lipow GW (2012) Solving the climate crisis through social change: public investment in social prosperity to cool a fevered planet. ABC-CLIO, Santa Barbara

Martinez ANG (2015) Being human in a consumer society. Ashgate Publishing, Farnham

PMI (2013) A guide to the project management body of knowledge (PMBOK guide), 5th edn. Project Management Institute, Newtown Square

Rockart JF (1981) A primer on critical success factors. In: Bullen CV, Rockart JF (eds) The rise of managerial computing: the best of the centre for information systems research. Dow Jones-Irwin, Homewood

Zeemering ES (2014) Collaborative strategies for sustainable cities: economy, environment and community in baltimore. Routledge publishing, London, 176p

Part IV
Case Studies on Environmental Conservation and Remediation Projects

Chapter 18
Case Study of Environmental Projects in Australia

In order to share some lessons learned from conceptualization to delivery of environmental conservation and remediation projects, one case study each from Western Australia, Australian capital territory (ACT), New South Wales, Queensland, Victoria, South Australia and Tasmania has been reviewed to demonstrate the approaches to reducing environmental effects in terms of reuse and redevelopment strategy, maximum use of depleted natural resources, maximum utilization of waste products, and so on (see e.g., Turner and Ward 2002).

18.1 City of Stirling Natural Environment Coastcare, Western Australia

18.1.1 Problem/Challenges

The Western Australian coastline hosts a remarkable 1,227 vascular plant species, about the same number of species as found in the entire British Isles, with just over 10 per cent (166 species) considered weeds (Beard 1990). This equates to the richest and most diverse native biodiversity of any mediterranean coastal region (Dixon 2011).

With no initial funding, a small group of local residents sought partnerships and support from a variety of sources to enable them to commence site surveys, develop a weed mapping and management strategy, compile flora and fauna species lists for the area, and plan a comprehensive approach to the rehabilitation of this region.

18.1.2 Project Detail

The work of Stirling Natural Environment Coastcare (SNEC) both in protecting the Stirling coastal zone and raising awareness of the need to conserve environmentally

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sensitive areas contributes significantly to the sustainable use and management of Western Australia's coastal environment.

The group is passionate about future land area use planning and has dedicated a vast amount of time, effort and resources to the preservation of the unique foreshore vegetation of the area. 2,395 volunteer hours were committed to the project between January and December 2009. To date, the group has managed and rehabilitated a total area of 32,959 square metres (SNEC 2014).

18.1.3 Project Outcome

Key achievements of the SNEC group include the followings;

- use of aerial mapping (i.e., photogrammetry discussed in Chap. 10) of the coastline,
- development and implementation of a series of education activities with Edith Cowan University, Western Australia,
- participation of the group in the Department of Education Community Service Program to improve the visual amenity of the coastline in coordination with local schools,
- planted 8,800 native seedlings,
- removed weed infestations by hand totalling more than 780 bags, and
- installed 180 square metres of weed matting.

The group continues to maintain and monitor all of the project sites, and are actively assessing surrounding areas with a view to linking existing rehabilitation efforts with future projects.

18.2 Whole of Paddock Rehabilitation Program, Australian Capital Territory

18.2.1 Problem/Challenges

Although there is increasing understanding of the problems and issues facing degraded woodlands in agricultural landscapes, the greatest environmental challenge is finding practical and cost effective solutions for rehabilitating these areas. In 2006, Greening Australia Capital Region (GACR) developed the Whole of Paddock Rehabilitation Program (WOPRP) an innovative approach to combating growing land degradation problems, restoring paddock health and providing multiple production and conservation benefits on the farm.

18.2.2 Project Detail

Whole of Paddock Rehabilitation Program (WOPRP) integrates conservation with production, by returning native trees and shrubs back into grazing systems. Whole paddocks greater than 10 ha are direct seeded with wide vegetation belts covering around 30 % of the paddock. Farmers receive a stewardship payment of $50/ha/year for a 5 years period while the native vegetation reaches 'escape' height. The program integrates large scale revegetation into commercial grazing or mixed grazing enterprises to improve both the conservation and production values of the site. These include increased shade and shelter for livestock, improved native pastures that are more drought resistant, the provision of a supplementary feed source for livestock and a potential to reduce parasite load.

18.2.3 Project Outcome

In 2008, WOPRP attracted over $200,000 from the Lachlan Catchment Management Committee and Department of Environment and Climate Change. Two pilot programs were successfully delivered in 2 different regions to "test drive" the initiative. Demand has exceeded supply with a significant and growing waiting list of more than 30 hopeful farmers.

18.3 Hybrid Air Conditioning Systems, New South Wales

18.3.1 Project Challenge/Objective

Buildings are responsible for about half of the total energy consumption of our modern society, and a large proportion of this is due to the operation of heating and cooling systems. Small capacity air conditioners, although economically attractive, do not usually offer much better energy consumption levels compared to large air conditioners, due to unreliable controls. There is increasing interest amongst researchers and industry in the use of solar panels to reduce electricity consumption (see also Othieno and Awange 2015).

The University of Technology, Sydney in New South Wales, used a Research Seeding grant to test the operation of a newly developed direct expansion hybrid solar air conditioning system, to determine how to best optimise its performance and energy consumption. Direct expansion (DX) air conditioning plants are simpler in configuration and more cost-effective to maintain than central cooling plants that use chillers and cooling towers. Known as 'Green Automation' this area of research focusses on the use, control and automation technologies required to achieve reliable use of renewable energy sources and the reduction of greenhouse gas emissions.

18.3.2 Project Detail

The research was carried out using an experimental solar DX hybrid air conditioner together with its programmable logic controller device. The air conditioner was installed in a 38 m^2 room with an external condensing unit, which was combined with a solar vacuum collector.

The air conditioning system was fully-instrumented with high precision sensors to measure a variety of operating variables including meteorological parameters (solar radiation, air temperature and relative humidity), water temperature in the solar storage tank, temperature and humidity in the test room, refrigerant temperature and total power consumption of the plant. The system performance was tested under various weather conditions. Daylong tests were carried out for 24 h with all measured data being monitored at 10 min intervals.

The energy efficiency of a DX air conditioner is closely dependant on the thermodynamic properties of the refrigerant before and after it leaves the condensing system. The key aim of the research was therefore to minimise the temperature of the refrigerant leaving the condenser in order to increase operating performance.

18.3.3 Project Outcome

The research has tested a new design that uses a three-way valve to regulate the flow of the refrigerant depending on ambient conditions and cooling demand. During periods of low demand (when condensing temperature is low), the control valve sends the refrigerant directly through a new bypass line to the condenser. During periods of high demand (when condensing temperature is high), the refrigerant goes through the normal pathway to a copper coil inside the water tank where a heat exchange occurs.

The new design allows the system to operate at a lower temperature after the refrigerant passes through the air-cooled condenser, which results in a significant increase in the overall operating performance. Furthermore, the lower refrigerant temperature leaving the condenser decreases the refrigerant temperature entering the evaporator, which in turn increases the cooling or refrigeration effects. The research has concluded that optimising refrigerant temperature in solar air conditioners can result in an average power saving of 11.4 % compared to uncontrolled operating conditions.

Execution of this project has substantially increased researchers' understanding of the operation of solar hybrid air-conditioning systems and provided key evidence that the modified design tested is capable of saving energy and reducing greenhouse gas emissions. Two larger research projects are now being proposed to further explore the use of green automation technology in reducing greenhouse gas emissions and energy costs associated with residential air conditioning systems.

18.4 East Trinity Remediation Project, Cairns, Queensland

18.4.1 Project Background

East Trinity inlet, a quiet tidal creek bordering the township of Cairns, Queensland, has witnessed a transformation in the last decade that has made it one of the world's most successful demonstrations of how to restore an area severely affected by acid-sulfate soils.

18.4.2 Project Challenge/Objective

The acid crisis at East Trinity began in the 1970s when developers drained and cleared 740 ha of tidal wetland to grow sugarcane. This dried underlying acid-sulfate soils, causing them to release slugs of acid whenever they were soaked by rain. Such acid release can in turn mobilise toxic levels of iron, aluminium and heavy metals, and can also degrade steel pipes and concrete structures to the point of failure.

Over the subsequent 25 years, it is estimated that 72,000 tons of sulphuric acid were released into Trinity inlet. Creeks became sterile, stained with the iron-red deposits from the acidification process. Adjacent mangrove ecosystems and associated wetlands were badly degraded, experiencing repeated fish kills in areas that were prime nurseries for coastal and reef waters. Birds, plants and animals also disappeared (see, e.g., Fisher et al. 2009; CRC CARE 2014a, b).

18.4.3 How the Project Was Carried Out

In 2001, the Queensland government purchased the land to remediate the acidic soils and protect the natural green backdrop to Cairns. A team led by CRC CARE program leader, Dr Richard Bush of Southern Cross University, restored the acid sulfate soils of below pH_3 to near-neutral in around one year, using an approach known as lime-assisted tidal exchange (LATE). This approach was considered to be extremely cost effective, compared to traditional practices, which would have cost over $300 million and required complete vegetation clearing. They re-introduced a partial tidal exchange through adjustable floodgates, allowing the most acidic sediments to be strategically re-flooded, which prevented them from producing more acid. Where the runoff was still too acidic they added hydrated lime using specially designed equipment.

18.4.4 Project Outcome

Gradually the mangroves began to colonise areas newly flooded with seawater. A wider range of mangrove species than the scientists had dared hope for have re-established, and fish and other marine life are now common in creeks that once ran so acid that nothing could survive in them.

Over 40 species of birdlife have returned to the East Trinity site following restoration. The success of this innovative project has led to a decision by the Queensland government to adopt the strategy across the entire East Trinity site. With an estimated 40 million hectares of similar acid coastal wetlands round the world, and at least 4 million in Australia, including parts of the Murray–Darling system, there is clear scope to apply much of the science and experience developed at Cairns (CRC CARE 2014a, b).

18.5 Regent Honeyeater Habitat Restoration Project, Victoria

18.5.1 Project Background

The Regent honeyeater habitat restoration (RHHR) project is a landscape scale community effort to protect and restore all significant remnants of native woodland habitat in the agricultural district of the Lurg Hills, near Benalla, Victoria (RHE 2014). While focus is placed on the Regent Honeyeater, many other declining birds and mammals also benefit from the restoration project.

In simplified ecosystems, like the typical Australian temperate rural landscape, insect populations are high and they attack remnant native trees more voraciously than they do in undisturbed bushland due to boosted nutrient levels in the foliage. With no shrubs or understory present, there are fewer birds and wasps to pull the insects back into line. Exacerbated by drought, the remnant vegetation experiences severe *rural dieback*. The ecosystem has lost its capacity for resilience; it's out of balance.

The RHHR project has seen great integrated results including the planting of more than 456,425 indigenous plants on over 420 individual sites, with a grand total of around 1,274 ha of habitat restored from 1997 to 2010. Not only are environmental outcomes significant but the community has also benefited with cooperation and networking between many different groups including landholders, schools, work for the dole, landmate team from Beechworth prison, corporate and community group volunteers, altogether totaling over 22,000 individuals, have been involved over the past 13 years (RHE 2014).

18.5.2 Project Challenge/Objectives

This well established revegetation project focuses on the Regent Honeyeater, an endangered bird species that has declined seriously over recent decades. Only about 1000–1500 of these striking birds remain in the wild and there are just 3 key habitats left in Victoria! The Lurg district, as one of these areas, provides essential nectar supplies for Regent Honeyeaters when they arrive each winter to feed on the flowering Ironbarks. After 150 years of clearing and grazing, remnants of the former Mugga Ironbark forest are scattered across the landscape as narrow strips on roadsides and small patches on private land. With increasing fragmentation and grazing pressure, the natural ecological balances of healthy bushland have been predominately lost (Davidson 1996).

The issues encountered during project include the following:

- Drought.
- Flood.
- Predation by kangaroos on revegetated sites.
- Regenerating issue—conventional planting doesn't succeed; the trees simply take up too much water and the little seedling just can't compete.
- Establishing smaller and rarer species, germination difficulties and vulnerabilities to rabbit predation.

The RHHR project aims to protect, restore, enlarge and connect the existing Box Ironbark habitat in the Lurg district of Victoria as fast as possible in order to restore the ecological balances and protect these fragile species. The key objectives include the following:

- Restore the natural box Ironbark ecosystem balance.
- Conserve key local and threatened/endangered fauna species-The Regent Honeyeaters, Grey-crowned Babblers, Brush-tailed phascogales and sugar gliders.
- Conserve locally threatened and endangered flora species-remnant Box Ironbark bushland (critical habitat).
- Increase understory grasses and shrubs in order to ensure survival of remnant 'habitat trees'.
- Connect fragmented habitat areas by linking remnant bush land patches, thus creating bio-links.
- Engage and educate the community and landholders.
- Undertake studies to learn more about conserving species in Box Ironbark forests.

18.5.3 Project Outcome

Team work and sense of community is something special which inspires many people and helps build stronger communities. The RHHR project also offers a social outlet with a chance for volunteers to meet new friends.

Landholder engagement and involvement is particularly important as it enables remnant patches of bushland to be linked over the landscape scale, connecting fragmented species. It also offers a chance for the landholder community to engage with one another, network, and strengthen community ties, offering a chance for information to be shared, conserving biodiversity for future generations to enjoy and providing public environmental goods, such as clean air, aesthetic landscapes and improving water quality. Project total outcome from 1996 to 2011 include the following;

- 346 fenced sites,
- 223.6 km of fencing erected,
- 1300.7 ha of habitat protected,
- a grand total of 488,925 seedlings planted,
- 489,363 seedling propagated,
- 50 sites direct seeded,
- 418 nest boxes placed,
- 136 private landholders involved, and
- 25,699 volunteers involved.

18.6 Goolwa Biodiversity Protection and Restoration Project, South Australia

18.6.1 Project Challenge/Objectives

Goolwa-to-Wellington Local Action Planning (GWLAP) Association works with the local community to protect and restore biodiversity and sustainably manage natural resources, so as to create an environment where human activity and natural ecosystems can sustainably co-exist. The body works within the Lower Lakes area, which is situated in the south-west corner of the Murray Darling Basin and covers approximately 265,000 ha.

18.6.2 Project Detail

Goolwa, which means "elbow" in local Aboriginal language, is a historic river port on the Murray River near the Murray Mouth in South Australia, and joined by a bridge to Hindmarsh Island. The Goolwa biodiversity protection and restoration project was a fantastic opportunity for the GWLAP association to transform a once barren paddock into a bio-diverse site, and has provided group members with experience in the management and monitoring of a revegetation site that has to contend with management issues such as rabbits, kangaroos, droughts and weeds. The group members also gained a greater understanding of the nearby vegetation communities through the undertaking of seed collection, propagation, and through the undertaking of bird surveys on the site.

The project site is situated close to the Finniss River, the second largest river in South Australia. The river is regarded as a biodiversity hotspot due to several large areas of remaining vegetation, populations of rare native fish, birds and plants. It is regarded as an important catchment for environmental flows into the Lower Lakes and Coorong wetland of international significance. The site is flanked by remnant vegetation with the river boasting some huge old river red gums and permanent waterholes (EHFC 2014).

18.6.3 Project Outcome

Since its inception in 1998, the GWLAP group members planted 1,446,476 local native seedlings to enhance and extend the wildlife habitat over an area of 8,288 ha on a site, which had suffered the effects of land clearance and alteration resulting from stock grazing and past land uses (CRC CARE 2014a, b). This project increased biodiversity in the area by planting back species that are known to occur naturally in the area. Revegetation enhanced the current habitat known to support the vulnerable yellow-tailed black cockatoo that use the large hollows found in the old red gums along the river and increased biodiversity and helped to decrease erosion.

18.7 Restoring Critical Riparian Areas in Southern Tasmania

18.7.1 Project Challenge/Objectives

The Southern Coastcare Association of Tasmania Inc (SCAT) is a not-for-profit umbrella organisation for a number of Coastcare groups in Southern Tasmania. SCAT is an innovative leader and supporter of community action for the management of the coastal environment in Australia.

Many water ways in Southern Tasmania are degraded by factors such as pollution, littering, clearance of native vegetation, invasion of environmental weeds and lack of appreciation and understanding by local communities. The purpose of this project was to support and facilitate community involvement in the protection and restoration of local water bodies with the aim to restore water quality across the region.

18.7.2 Project Detail

Qantas Foundation Project funding supported natural resource management of approximately 10 ha of native habitat and the long term improvement of water quality in five water bodies. The project engaged five local volunteer groups to protect and repair their "local patch", inspiring residents to value and care for their local waterways. On-ground works included revegetation, primary weed removal, rubbish removal, construction of pedestrian walk ways and placement of boulders to reduce vehicle access.

18.7.3 Project Outcome

Project total outcome between 2009 and 2011 include the following;

- 1,750 native plants propagated,
- 3,890 natives seedlings planted,
- 2.7 ha revegetated,
- 8.75 ha of area weeded,
- 73 regular volunteers from 5 Landcare groups,
- 910 local volunteer hours which equates to approximately $27,300 work,
- 312 volunteers participated in over 50 training and community planting days, and
- involvement of three local councils and 5 Landcare groups.

18.8 Concluding Remarks

One of the challenges Australia faces in addressing threats to ecosystems and biodiversity is that, while impacts are observable in many ecosystems, threats to some species attract greater public awareness and concern than others. For less high profile species, severe impacts often go unnoticed. Most people are not aware of the devastating decline in biodiversity within existing local communities, for example, but have great concerns about the impact of climate change on iconic animal species.

Similarly, invasion of environmental weeds (e.g., phytophthora dieback) is a threat to biodiversity that has a relatively low profile outside affected areas, and there is a legitimate concern that its spread may become even more vigorous under changed climate conditions.

It is evident from the series of case studies reviewed that significant improvements in the public awareness of threats to biodiversity can be achieved by cooperative environmental projects involving a range of community stakeholders. Regent honeyeater habit restoration project in Victoria provides a commendable example of how private sector organisations, volunteer groups, landowners and governments can combine resources and work together to achieve positive environmental outcomes and engage the community.

References

Beard JS (1990) Plant life of western Australia. Kangaroo Press, New South Wales

CRC CARE (2014a) Cooperative Research Centre for Contamination Assessment and Remediation of the Environment, CRC CARE case studies, Mawson Lakes, South Australia. www.crccare.com/our-research/case-studies. Accessed 16 June 2014

CRC CARE (2014b) Cooperative Research Centre for Contamination Assessment and Remediation of the Environment, CRC CARE case studies, East Trinity Remediation Project, Cairns, Queensland. www.crccare.com/our-research/case-studies. Accessed 16 June 2014

Davidson I (1996) Box-ironbark remnants project. Department of Natural Resources and Environment, Melbourne

Dixon K (2011) Coastal plants: a guide to the identification and restoration of plants of the perth region. CSIRO Publishing, Clayton

EHFC (2014) Enhancing Habitat in the Finniss Catchment, South Australia. www.landcareonline.com.au. Accessed 18 June 2014

Fisher J, Lindernmayer DB (2002) The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. 2 Paddock trees as stepping stones. Biodivers Conserv 11:833–849

Fisher J, Stott J, Zerger A, Warren G, Sherren K, Forrester RI (2009) Reversing a tree regeneration crisis in an endangered ecoregion. Proc Natl Acad Sci 106(10386):10391

Gibbons P, Boak M (2002) The value of paddock trees for regional conservation in an agricultural landscape. Ecol Manag Restor 3(205):210

LCMA (2009) Lachlan Catchment Management Authority. Introducing whole of paddock rehabilitation (WOPR): a new approach to regreening the farm, greening Australia, 23 p. www.greeningaustralia.org.au/project/whole-of-paddock-rehabilitation. Case study. Accessed 15 Feb 2015

Othieno H, Awange J (2015) Energy Resources in Africa: distribution, opportunities and challenges. Springer international publications, Heidelberg

RHE (2014) Regent honeyeater project. http://regenthoneyeater.org.au/grn.php. Case study. Accessed 16 Jan 2015

SNEC (2014) Stirling natural environment coastcare case studies. www.stirlingnaturalenvironmentcoastcare.com. Accessed 18 June 2014

Turner NC, Ward PR (2002) The role of agroforestry and perennial pasture in mitigating water logging and secondary salinity: summary. Agric Water Manag 53(271):275

Chapter 19
Case Study of Environmental Projects in Developing Countries

Management of environmental projects in developing countries in terms of pollution restoration and reuse of industrial wastes are sufficiently different to warrant the inclusion of a chapter in a book on environmental project management. The type and size of challenges and the environment in which they are applied are different. So also is the resources that are employed, and the way the projects are funded. The chapter first reviews some of the main issues that contribute to the distinctive nature of developing countries and how these affect their environmental protection/remediation as well as waste reduction projects.

19.1 Hydrocarbon Pollution Restoration Project, Ogoniland, Nigeria

19.1.1 Project Description

The prevailing environmental degradation and pollution resulting from oil spillage in Nigeria has brought out anew, the challenges that the country faces if it fails in its quest to curtail environmental menaces and degradation. The unending oil spillage and pollution coupled with increasing spate of desertification have compelled some analysts to conclude that the country's environmental problem is intractable.

At the request of the government of Federal Republic of Nigeria, the United Nations Environmental Programme (UNEP) was commissioned in 2009 to assess the environment of Ogoni land, Niger Delta region, River State of Nigeria, which covers contaminated land, groundwater, surface water, sediment, vegetation, air pollution, public health, and provide recommendations for remediation.

Adhering to the UNEP's recommendation and responding to the grievances of the Ogoni people, the hydrocarbon pollution restoration project (HYPREP) was established in 2011 to fully implement recommendation proposed in the UNEP's

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environmental assessment report. An initial sum of US$1 billion was proposed by the UNEP to cover the first five years of clean-up operations.

19.1.2 Project Challenges and Objectives

After the United Nations environmental programme (UNEP) made their recommendations on the environmental impact of hydrocarbons exploration in Ogoniland, the President of the Federal Government of Nigeria set up a Ministerial Committee to suggest appropriate actions on them. The committee was set up as a direct response to the recommendations of the United Nations Environment Programme (UNEP) to correct cases of environmental degradation in Ogoniland and other vulnerable environments in Nigeria affected by oil pollution. However, as of the time of writing this book (March 2015), not a trace of clean-up has commenced in the impacted areas. Although, oil production stopped in Ogoniland in 1993, some of the equipment wasn't fully decommissioned, leaving it open to sabotage and corrosion (UNEP 2015a, b).

19.1.3 Environmental Monitoring Tools Used in Ogoniland

19.1.3.1 Geographical Information Systems (GIS)

GIS mapping/cartography, discussed in Chap. 12, was used extensively in the Ogoniland assessment with more than 200 maps generated at a scale of 1:5,000. A 1:50,000 cartographic atlas was also produced, giving all those working in the field access to the same information. The atlas was frequently updated as new data arrived from the field.

Spatial analyses included proximity analysis, which recorded the distances between contaminated sites and community wells and settlements, as well as contaminant dispersion. Statistical analyses were carried out, for instance on shifts in land cover, changes to land-cover classification and areas of land impacted by contaminated sites. In addition, groundwater modelling was carried out to generate contaminant-plume contours and to depict groundwater flow direction.

19.1.3.2 Remote Sensing

The components of the environmental assessment of Ogoniland in which remote sensing, discussed in Chap. 11, played a key role were: land-use study, for example tracking changes in land cover; vegetation surveys, including impacts of oil on mangroves; assessing pollution of creeks and other water bodies; and research into the artisanal refining of crude oil in primitive stills (see e.g., Fig. 1.2 on p. 6).

19.1.3.3 Global Navigation Satellite System (GNSS)

A large number of global navigation satellite system (GNSS) instruments, such as the ones discussed in Chap. 9, were used to record geographic coordinates of pollution on the ground and the points from which samples were collected by the different thematic teams. The GNSS was also used to map the road network and accessibility for the purpose of planning daily transportation to and from sampling sites.

19.1.4 Project Outcome

As shown from the information provided above, although modern environmental monitoring tools were employed, it is very clear that the project was poorly planned from the outset, hence the reason for the poor performance. After nearly two decades of the site being abandoned, the scientific study revealed that there was still widespread pollution of the Niger Delta that placed the local communities at direct risk. The ousted Minister of Petroleum Resources, Mrs Diezani Alison-Madueke, said in 2014 that apart from the transitional phase of the project as recommended in the UNEP report, the government had not achieved the major objective of cleaning up the area (UNEP 2015a, b).

19.2 Waste to Wealth Programme: Nigeria, Kenya, Uganda, Cameroon

Living Earth Foundation's multi-country "Waste to Wealth" project is responding to the urgent need to improve the lives of the increasing number of improvised and vulnerable people residing in urban slums in sub-Saharan Africa alongside ANPEZ Centre for Environment and Development, its local project partner in Port Harcourt Nigeria as well as the living earth foundation in Kampala (Uganda), Nairobi (Kenya), and Douala (Cameroon).

19.2.1 Programme Objectives

The project is creating a virtuous circle wherein slum dwellers in nine urban areas in the cities of Port Harcourt (Nigeria), Nairobi (Kenya), Douala (Cameroon) and Kampala (Uganda), take responsibility for collecting and managing household solid waste, instead of sending this off to landfills. Social ventures and micro-enterprises are currently overseeing the process of sorting waste, recycling and reuse.

The project is ensuring environmental sanitation improvements are being sustained, with subsequent benefits in the health and well being of slum inhabitants. The project is fostering the emergence of a skilled and effective business sector wherein social enterprises, founded by and in poor urban communities, are deriving wealth from the provision of environmental services and derivative recycling and re-use activities. The waste is therefore becoming the catalyst for their income generation and creating employment opportunities.

19.2.2 Programme Background

For the first time in history, over half the world's population lives in urban areas. The trend of urbanisation is expected to increase markedly, particularly in sub-Saharan Africa where the urban population is forecast to double between 2000 and 2030. Of this urban population, over 70 % live in slum conditions with the associated problems of underemployment, low household income, and widespread poverty.

The growth in population is placing increased demand on the urban environment; there is the same amount of land but more people; the same number of toilets but more human waste; more rubbish and even less space to dispose of it. Widespread poor solid waste management creates associated health problems and poses a threat to surface and groundwater quality. The onus for managing the physical environment in poor areas remains with the communities themselves: if they don't address the problems of household waste, poor public sanitation, clogged and disease-spreading drainage, no-one will do it for them.

19.2.3 Programme Outcome

- Sustained environmental sanitation improvement, with subsequent benefits in health and well-being for the inhabitants in the 9 target communities through improved service provision as a result of partnerships involving local governments, the private sector and civil society;
- The emergence of a skilled and effective business sector wherein social enterprises, founded by and in poor urban communities, derive wealth from the provision of environmental services and derivative recycling and re-use activities;
- The role of women in the sector will be promoted;
- Improved awareness amongst all stakeholders; including policy-makers, on the rights and entitlement of poor urban dwellers to a clean environment and of the potential to harness local cost-effective resources to deliver these rights;
- Enhanced capacity among local authorities to engage in public-private partnership (PPP) development, particularly involving the less formal private sector. Strengthening managerial, technical and organisational abilities of municipalities and addressing statutory limitations will play a key part in achieving this result;

- Improved South-South linkages and networking between partners and associates to increase learning, information dissemination, consensus building and advocacy skills with which to influence policy makers.

19.3 Concluding Remarks

This chapter provides an overview of the state of environmental degradation in developing countries. Poor economic growth has resulted in an increase in the poverty level and migration from rural areas to the urban areas has resulted in unplanned settlements in suburban areas. Illegal dumping of wastes on the river banks or on the roadside poses environmental and economic threats on nearby properties, exacerbating the vulnerability of surface and groundwater condition. Local authorities rarely consider environmental impact in siting contaminated sites.

Developing countries should look beyond the induced notion that technological advancement and economic growth is a panacea for environmental degradation. There is need for an urgent paradigm shift from the present means of promoting economic growth in which CO_2 emissions and other forms of environmental degradation are inherent. Studies conducted by several researchers (see e.g., Grossman and Kruger 1995; Ang 2008; Machado 2000; Shafik and Bandypadhyay 1992) stressed that economic growth will not automatically lead to higher environmental quality, but only via strong pressure for stronger environmental policy. The quality of policy and institutions can significantly reduce environmental degradation even at low income levels and speed up improvements at higher income levels (Panayotou 1993). Apart from adopting stringent measures of environmental protection, ecological friendly means of economic growth must also be pursued.

Waste creation is part of human endeavour but the disposal is often neglected until the appropriate local government creates incentives, preferably market-based incentives, that will encourage both people and enterprises to dispose their waste in an appropriate way. This is paramount because the implication of proper waste disposal has led to a huge expenditure on public health, reduction in productivity of the populace and reduction of life expectancy. When waste management service is delivered and cost paid for by the waste generator (providing employment), it means waste has also provided wealth, which can be construed as "waste-to-wealth". With this extension, effective waste management has become not only service but an instrument for fighting poverty. Government of developing countries should not only conceive waste management program as a service, but as a war against poverty and poor condition of living, using environmental project management principles, methods and processes discussed in this book.

References

Ang JB (2008) Economic development, pollutant emissions and energy consumption in malaysia. J Policy Model 30:271–278

Grossman GM, Krueger AB (1995) Economic growth and the environment. Q J Econ 110(2):353–377

Machado GV (2000) Energy use, CO_2 emissions and foreign trade: an input-output approach applied to theBrazilian case. In: Paper presented at the 13th conference on input-output technique, Italy, 21–25 Aug

Panayotou T (1993) Empirical tests and policy analysis of environmental degradation of different stages of economic development. In: Working paper WP238, technology and employment programme, International labour Office, Geneva

Shafik N, Bandypadhyay S (1992) Economic growth and environmental quality: time series and cross sectional evidence. In: Background paper for world development report, World Bank, Washington D.C

UNEP (2015a) United Nations Environmental Programme (UNEP) report on Environmental Assessment of Ogoniland (4 August 2011). www.unep.org.org/nigeria/. Accessed 15 Mar 2015

UNEP (2015b) United Nations Environmental Programme (UNEP) report, n. 45, 94 200. www.unep.org/nigeria/. Accessed 15 Mar 2015

Chapter 20
Challenges of Applying EnvPM in Developing Countries

Practically all aspects of business today involve environmental considerations. These considerations, in turn, are being integrated into more and more projects as companies in all industries realize it is not just good public relations but good business too. But environment-related projects are fraught with special risks and difficulties. In carrying out these kind of projects (e.g., altering a manufacturing processes to reduce pollutant), the project manager is confronted with many challenges in addition to the customary constraints of time, budget, quality, resources, etc. These include challenges, such as environmental regulation compliance, responding to public scrutiny, addressing societal values, handling business-government interactions and ensuring workers' health and safety.

Project managers must be able to carefully take into account the environmental consequences of their actions. The size and composition of the project team will depend on the complexity of the environmental issue and the time, budget and other resources available.

20.1 Projects and Project Management

Project management has gained popularity as a distinct management concept used to drive not only business, but also social, economic and industrial development objectives in developing countries. Several programs, such as product development, event planning, real estate development, poverty reduction programs and integrated waste-management systems all lay heavy emphasis on the use of projects and project management as a tool to optimize the rate of success. Most developing countries, whose economies had been transformed into market-oriented environments have been fuelled by years of significant economic growths resulting in urgent needs to improve all facets of project management operations as they are accelerating their strategy of industrialization, modernization, and globalization with the execution of all kinds of projects of increasing diversity and complexity in a wide variety of industries, including the environmental industry. As a result, project management

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profession has been evolving rapidly in recent years in these countries, providing a competitive advantage over those who are slow in adapting project management principles and methodologies to their development programmes.

As far back as the mid-1960s, the accelerated provision of infrastructure in the aftermath of colonization saw the emergence of the practice of project management as a tool for the delivery of developmental initiatives in the developing countries. However, as this development became driven by donor-funded interventions, the dictates of donors, who were actively funding the development and restructuring of all sectors of the economy of developing countries, propelled the prominence of project management in the 1980s as a better alternative for delivering development interventions (Ofori and Sakyi 2006). A case study showing one of the challenges of applying environmental project management in developing countries is the Nigeria's hydrocarbon pollution restoration project discussed in Sect. 19.1.

20.2 Sustainable Waste Management Challenges

Sustainable waste management means reducing the volume of waste at source, improving sorting, and increasing recycling and waste recovery in the form of energy or compost (see, e.g., Othieno and Awange 2015). However, developing the waste sector requires investment and competencies that the public sector is not always in a position to provide. Local authorities are therefore turning to the private sector, hoping to benefit from its know-how and competitive prices.

Every year, developing countries spend some US$46 billion on managing their municipal solid waste of around 2.5 billion tonnes/year, and these investments could exceed US$150 billion/year by 2025 (Durant 2013).

Ever-increasing amounts of municipal solid waste, accompanied by rapid economic and population growth makes it increasingly difficult for local authorities (municipalities) in the developing countries to sustainably manage their solid wastes (see e.g., Thomas-Hope 1998). The increase is primarily attributable to the developing nations' economic development, driven by the combined effect of strong urban development and population growth. Waste management in these countries is a major challenge for the years ahead: the negative external impacts of solid municipal waste are serious, including in particular major impacts on the environment and human health, as open waste dumps remain the dominant processing mode in developing countries. Constrained by limited financial resources, towns and cities of these countries are struggling to deal with the proliferation of municipal solid waste. To some extent, recycling and recovery activities are not affected by budgetary limitations. Also with energy and raw materials becoming more and more expensive, this should be seen as a major opportunity for developing the solid waste sector (see, e.g., Othieno and Awange 2015).

20.3 Proposed Solution to Waste Management Challenges

While it is indisputable that human and other organic wastes are few of the largest wastes generated daily, harnessing the energy content in these will go a long way to aid the abatement of greenhouse gas emissions and stem the growth of climate change (Akindeju 2015). Household biogas technology would be a good option for turning municipal solid wastes (e.g., human waste, animal waste, organic kitchen waste, garden waste, or a mixture of any of these) into a renewable energy resources (see, e.g., Othieno and Awange 2015). It is claimed that the energy extracted from organic kitchen and pet waste alone is capable of generating enough gas to cook three meals daily (Deublein and Steinhauser 2011). Biogas technology also produces a clear organic liquid fertilizer that can be spread on gardens. It is an "easy-to-develop" type of technology that remains vastly under-utilized (see Fig. 20.1). Although, a significant amount of CO_2 is produced during biogas methanation process, the CO_2 is easily contained, captured and scrubbed, and hence, not released into the atmosphere.

There are many benefits to be derived from the process of converting substrates in a biogas plant. These include:

- Substantial reduction in the disposal costs of organic wastes, even including meaningful reuse (e.g., fertilizers), because the quantity of biomass decreases by up to 50 %.
- Reduction of landfill area and the protection of groundwater: the quantity of organic waste materials can be reduced to about 4 % sludge when the residue is squeezed off and the wastewater from the biogas plant is recycled into the sewage plant.
- Biogas residuals can be used as fertilizer because the wastes contain three main elements of fertilizer (NPK, NK or NP). The microbial agents do not deplete nitrogen (N), phosphorus (P) or potassium (P), hence the residuals are enriched with the fertilizer content, which can be recycled to agriculture.

Fig. 20.1 Household biogas technology: solution to municipal waste challenges

- Possible avoidance of a sewer connection and fees for the disposal of the wastewater, particularly with rural dwellings.
- Elimination of weed seeds: the longer weed seeds remain in the liquid manure, the more they are eliminated. Therefore, the growth of weeds and the spread of undesired plants in the fields are minimized.

Solutions to waste management problems in developing countries can also be found in the private sector, by developing integrated waste management systems and by improving recycling practices. The private sector is considered to be better equipped both in terms of financial resources and technology (e.g., home biogas technology) to deliver a quality service at a low price. However, it is important that succeeding in this sector calls for the closest possible proximity to the project environment: operating methods do not necessarily transpose well from one country to another.

20.4 Concluding Remarks

Developing countries, although poor, should develop area-specific solutions to their problems in the management of environmental pollutants and wastes. Rural economy first needs to be improved if rural-urban migration is to be managed. Involvement of various stakeholders (e.g., community-based organisation (CBO), non-governmental organisation (NGOs) and the private sector) through neighbourhood groups of people from middle and higher income groups and business organisations can provide the needed solution. Other measures include cultivation of a sense of clean environment through clean community awareness programmes.

References

Akindeju M (2015) Household BioGas System (HBS). In: CRIC research seminar held on the 9th of February, 2015 at Greenhill Enterprise Centre, Federation University, Australia, www.federation.edu.au/faculties-and-schools/federation-business-school/research/cric/events. Accessed 9 June 2015

Deublein D, Steinhauser A (2011) Biogas from waste and renewable resources: an introduction. Wiley, Weinheim, 578 pp

Durant D (2013) Sustainable waste management challenges in developing countries

Ofori DF, Sakyi K (2006) Proceedings of the Workshop Series on Project Management and Development, Woeli Publishing Services

Othieno H, Awange J (2015) Energy resources in africa: distribution, opportunities and challenges. Springer International Publications, Berlin

Thomas-Hope EM (1998) Solid waste management: critical issues for developing countries. Canoe Press, University of West Indies, Mona

Index

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Environmental Science and Engineering, DOI 10.1007/978-3-319-27651-9

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