INTEGRATED WATER MANAGEMENT

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INTEGRATED WATER MANAGEMENT

Practical Experiences and Case Studies

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TABLE OF CONTENTS

Acknowledgements ix

Preface xi

Introduction 1
Towards Integrated Water Management
P. Meire, M. Coenen, C. Lombardo, M. Robba, R. Sacile

PART I - Concepts and Approaches of Integrated Water Management 9

Filling the Information Gap between Water Systems and Decision Makers in the Sustainable Development of a Territory 11
F. Colaceci, C. Lombardo, R. Minciardi, M. Robba, R. Sacile

Towards an Adaptive Approach in Planning and Management Process 23
M.P. Rosa

The Value of the Italian Civil Protection System in Integrated Water Management for the Mediterranean Environment 33
F. Giannoni, G. Roth, R. Rudari

Knowledge Discovery in Environmental Data 51
J. Izquierdo, J.L. Díaz, R. Pérez, P.A. López, J.J. Mora

NetSyMoD - An Integrated Approach for Water Resources Management 69
C. Giupponi, A. Sgobbi, J. Mysiak, R. Camera, A. Fassio,

Water Conflicts: An Unavoidable Challenge from the Transboundary to the Local Dimension 95
A. Nardini, A. Goltara, B. Chartier

PART II - Case Studies 113

An Eco-Hydrological Project on Turkey Creek Watershed, South Carolina, U.S.A. 115
D. Amatya, C. Trettin

Integrated Transboundary Management of Lake Constance Driven by the International Commission for the Protection of Lake Constance (IGKB) 127
J. Bloesch, H.G. Schröder

Integrated Water Mangement in the Seven Cities Basin........ 141
T.P. Dentinho, J. Porteiro, H. Calado, E. Silva, J.C. Fontes, P. Borges J. Marques, R. Jonker, J. Ferreira

Establishment of the Iskar Reservoir Minimum Sanitary Storage Capacity 155
I. Dimitrova

Eutrophication in the Blackwater River Catchment, Ireland 171
P. Jordan, C. Ward, J. Arnscheidt, S. McCormick

The Proposal of IWRM in the Bouregreg Basin and How it Fits with the UNESCO/HELP Policy Program........ 179
A. Khattabi

Impact of the Ignalina Nuclear Power Plant on the Druksiai Cooler-Lake........ 189
J. Kriauciuniene, D. Sarauskiene

Transboundary River Contract Semois-Semoy Between Belgium (Wallonia) and France........ 199
F. Rosillon, J. Lobet

Ground and Water Levels Change in the Scheldt Basin 207
E. Masson, F. Meilliez

The Architecture of a Decision Support System (DSS) for Groundwater Quality Preservation in Terceira Island (Azores) 219
T. Dentinho, R. Minciardi, M. Robba, R. Sacile, V. Silva

Greece: Ecosystem Based IWM Plans in the Framework of WFD Implementation: The “Strymon” Pilot Project........ 233
S.G. Skias

The Role of the Help Programme 247
M. Bonell

Participation Aspects in the Realisation of the Nete River
Basin Management Plan: Methodology and Application 263
J. Staes, M. Coenen, P. Meire

The Use of Hydrological Characteristics for Wetland Habitats Protection
in Water Management of the Upper Narew River System.............................. 283
D. Miroslaw-Swiatek, T. Okruszko, J. Kubrak, I. Kardel

Saltwater Intrusion in a Unconfined Coastal Aquifer: The Case Study
of Cervia (North Adriatic Sea, Italy) 295
E. Ulazzi, M. Antonellini, G. Gabbianelli

International and Inner Transboundary River Basins in the Kaliningrad
Oblast, South-Eastern Baltic.. 309
B. Chubarenko, D. Domnin

PART III - Reports of the Working Groups... 323

Environmental Indicators for Water Resources Management 325
L.M (LES) Lavkulich, E. Ulazzi

Developments in Participation within Integrated Water Management 343
J.A. van Ast, M.P. Rosa, L.L.P.A. Santbergen

Conclusion.. 355
P. Meire, M. Coenen, C. Lombardo, M. Robba, R. Sacile

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PREFACE

It is widely stipulated that the world's water supply will come to symbolize the blue gold of the 21st century. As such, it is essential that further efforts be invested in developing practical means for managing this natural wealth, in order to avoid any possible threat of depletion, contamination or adverse side effects for the societies who depend on it.

Water is a limited resource, and human beings and their subsequent anthropogenic processes can cause subtle but drastic variations in its quantity and quality, which can in turn result in changes to the source's related ecosystem.

The EC directive 2000/60 introduced a whole range of specific definitions, objectives and constraints regarding the various aspects of water management, including water quality management, policies, economic aspects, ecology, price, and sustainable development. These issues all require the formulation of common, integrated, sustainable approaches for managing the water system from a multidisciplinary perspective, and the definition of new professional skills, requirements which become even more evident where transboundary areas are concerned. In order to take decisions in an equitable, sustainable, and ethical fashion, water resource management does in fact call for extensive knowledge of the complex relationships between citizens and their water system.

The book represents a practical contribution made possible thanks to the efforts of scientists from NATO countries and partners, along with Belgium and Italy's collaboration on Integrated Water Management and its possible risk factors, including problems related to targeted terrorist acts.

The results of the Pilot Study demonstrated the importance of addressing issues such as non-traditional threats to security, which could result in economic, social and political instability. In merging the Committee on the Challenges of Modern Society (CCMS) and the Science Committee into a single "Science for Peace and Security" (SPS) Committee, we hope to be able to continue guaranteeing conflict prevention in relation to resource-scarcity, so as to rise to the challenges inherent in a rapidly changing global security environment.

Brussels,
December 15, 2006

Ambassador Maurizio Moreno
Italian Permanent Representative to NATO

Ambassador Dominique Struye de Swielande
Belgian Permanent Representative to NATO

H.E. Sandro Maria Siggia
Ambassador of Italy to Belgium

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Chairman of the Board of Directors of the Belgian Science Policy Office

TOWARDS INTEGRATED WATER MANAGEMENT

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1. Introduction

Water is a “sine qua non” for life and, due to the increasing human population and our growing needs, the amount of water needed is increasing steadily (Gleick, 2003). On the other hand, the available water resources are declining. Furthermore, water is needed both for men and for all ecosystems.

The main question that has to be addressed is then, of course, how to use and divide the available water among all users (men and ecosystems) now and in the next generations. The water system can be seen as a kind of reactor, directing the precipitation through different pathways (physical, chemical and biological processes) back to the atmosphere or sinks like deep groundwater. A water system is:

“a coherent and functional unity of surface water, groundwater, riverbed, riverbanks and technical infrastructure, including the occurring plant and

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animal communities and all associated physical, chemical en biological characteristics and processes".

It is clear that the water system has been changed to a large extend to fulfil our water demands. It is equally clear that the way we are using and changing our water system is not sustainable. In recent years, the concept of integrated water (resources) management has been developed. The idea behind this concept dates back to the first UN conference on the human environment in Stockholm (1972), but mainly to the Conference on Water at Mar del Plata in 1977. The next step was the International Conference on Water and Environment in Dublin (1992) where ideas were put forward to the UNCED conference later that year in Rio. Within Agenda 21 this was incorporated:

"The holistic management of fresh water as a finite and vulnerable resource, and the integration of sectoral water plans and programs within the framework of national economic and social policy, are of paramount importance for actions in the 1990's and beyond. Integrated water resources management is based on the perception of water as an integral part of the ecosystem, a natural resource and social and economic good, whose quantity and quality determine the nature of its utilization. To this end, water resources have been protected, taken into account the functioning of aquatic ecosystems and the perenniality of the resource, in order to satisfy and reconcile needs for water in human activities" (Chapter 18, paragraphs 18.6 and 18.8)

So far, efficiency of water management was equated with maximum use of water resources by users (Calder, 1999). Environmental and ecological considerations as well as downstream users were given little attention. In a demand driven situation the response to water shortage was to augment the supplies, hence even more reducing the incentive to manage water in a sustainable way! This resulted in a severe deterioration of the natural functioning of the water system. This in turn impairs human use. The reduction of the flow e.g. can severely impact water use: it reduces the assimilative capacity and the discharge of pollutants may lead to toxic conditions and extra costs to public services for the treatment of water.

This brings us to a first crucial question: can we determine the carrying capacity of a water system and in what ways can we manage (increase) this carrying capacity. Carrying capacity of a watershed could be defined as the amount of water that is available for human use taking into account the amount necessary for the ecosystem so that they can still fulfil their ecosystem functions, which deliver essential ecosystem goods and services to our society. Related to the socio–economic system, the water system includes three groups of functions: sink, source and life support system. The pressures of using the water system as a source, a sink or a life support system, respectively have mainly impact on the water quantity; the water quality and on the services provided by the natural system and as a consequence immediately on the socio–economic system.

How multiple use and often-conflicting demands can be brought in line with what the natural system can support. During long time, water management has been approached mainly (or even only) from a technological viewpoint. The water system was engineered and problems were solved technically when they appeared. River systems have been manipulated in order to fulfil functions and conditions for human activity without considering consequences, unless some local ones. Therefore, problems were shift in space and time. In this way, the carrying capacity is not considered. All pressures on the natural water system have a feedback effect on human welfare and wellbeing, herewith starting a vicious circle by impacting the socio–economic system again. Preventing the start of this degradation spiral can only be reached by respecting the carrying capacity of the water system.

In order to determine the carrying capacity, a system approach is urged. Therefore, we have to consider the physical and the biological water system as well as the water use processes (water chains) and their interrelations. Land use plays a crucial role and especially agriculture and silviculture can have a pronounced impact on the availability of water. Further, the different storage mechanisms as well as efficiency of water use and reuse determine the carrying capacity. Therefore, shifting from policy and management mainly focussed on impacts on the sink to tackling pressures on source and life support is urgently needed. Combining all preconditions for preventing to pass the carrying capacity determine the so-called "environmental space". The services that have to be considered for the 'environmental space' are production, information and regulation.

It is necessary for each water basin to create a balance between the "functioning of the water system" and "the impact of the water chain" on it. Therefore, water uses should be tuned to the system and we should shift from adapting the system to the demand to adapting the use to the supply limits of the system. Since factors as technology, demography, society change, preconditions for the carrying capacity have to be dynamic.

Integrated Water Management is the tool to respect the necessary preconditions. If we can determine the carrying capacity, how can we then 'translate' the necessary conditions into planning and management? How to make these choices?

Sustainable development, protection of biodiversity, and the stand still principal are environmental principles that can influence the water system directly. The precautionary principle, a source oriented approach and rational water use should have an influence on the water chain as well as welfare and the human perception on the water system (Bergmans et al., 1999).

Thus, there is the increasing need of managing water resources integrating different issues (legislative, economic, environmental, social, etc.) in a sustainable way. This has become an important goal of both the national and the European governments (2000/60/EC water framework directive) and should be supported by the scientific community. Specifically, a major effort in the recent years was to combine the different fields of expertise necessary for water management (hydraulics, hydrology, water quality, ecosystem modelling, etc.) in order to build efficient Environmental Decision Support Systems (EDSS) for the planning and management of water resources at the different scales of intervention, in order to help decision makers and satisfy the different stakeholders.

The proposed book is the result of the research activity and the exchange of knowledge among a team of experts in different disciplines and institutions related to water resources. Specifically, people that present contribution in this book have had the possibility in the past years to have different kinds of connections and collaboration. Due to the very different methods of approach and the various environmental realities that characterized every research team, at first, it was very difficult to establish common objectives. However, thanks to exchange of students and/or professors, this group started to become more and more compact during the years. Scientific collaboration became more intensive also because of the participation of the most of these people to a pilot study called IWM (Integrated Water Management, supported by the Belgian Office for Scientific, Technical and Cultural Affairs (DWTC) in collaboration with the Office of the Scientific Attachè of the Italian Embassy in Brussels).

The main objective of the NATO/CCMS IWM pilot study is exchanging and combining expertise in water system research, considering different dimensions of water management and their intra and inter relations (see Figure 1). Specifically, the ”Integration of Knowledge” dimension represents the required competences; it includes natural scientific as well as social and economical aspects, considered as basic information about the functioning of water systems and the chains of the water users. The “Organizational Integration” dimension concerns all relevant competences and participation of stakeholders and means an important support for the efficiency of the water management. The “Legislative basis” dimension is the regulating basic framework including and combining all legal aspects.

The knowledge brought together by means of the pilot study, has to contribute to the knowledge of Integrated Water Management in general, including the necessary differentiation, given the wide variety of conditions in the different types of basins or watersheds. Therefore, both theoretical studies on the functioning of water systems, organisation and legislation as well as specific cases were discussed.

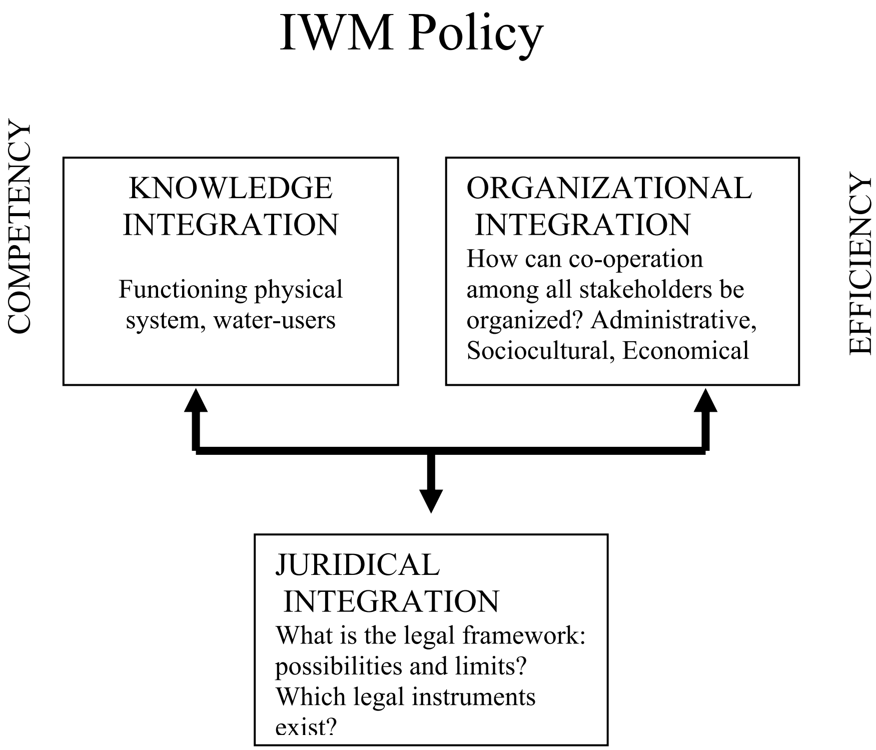

Figure 1. Different aspects of Integrated Water Management

2. Pilot Study

The pilot study on Integrated Water Management, supported by the Belgian Office for Scientific, Technical and Cultural Affairs (DWTC) and by the Italian Embassy in Belgium, was launched by the NATO Committee on the Challenges of Modern Society (CCMS) in November 2002 (http://www.nato.int/ccms). It was led by Prof. dr. P. Meire, University of Antwerp, Department of Biology and holder of the chair of Integrated Water Management at the Institute of Environmental Studies and Flemish Environmental Agency (VMM) and by Prof. Roberto Sacile from DIST-Dept. Communication Computer & System Sciences, University of Genova, Italy.

The pilot study addressed specific issues, requiring an integrated approach. During the pilot study, participants worked both during plenary meetings and in working groups. Participants belonged to research institutes, universities, governmental authorities and non-governmental organizations (NGOs).

The pilot study's final aim is to learn from comparison by presenting examples to build upon, to prepare publications of scientific papers with concepts, not detailed guidelines, to establish a network for initiating new projects and to enforce capacity building in all participating countries (see Figure 2).

Since the carrying capacity is a point of departure for the development of concepts for river basin management plans, participation and transboundary cooperation get main attention. An important input for these concepts is the comparison and evaluation of IWM in given basins. This information is the input of a NATO Advanced Research Workshop.

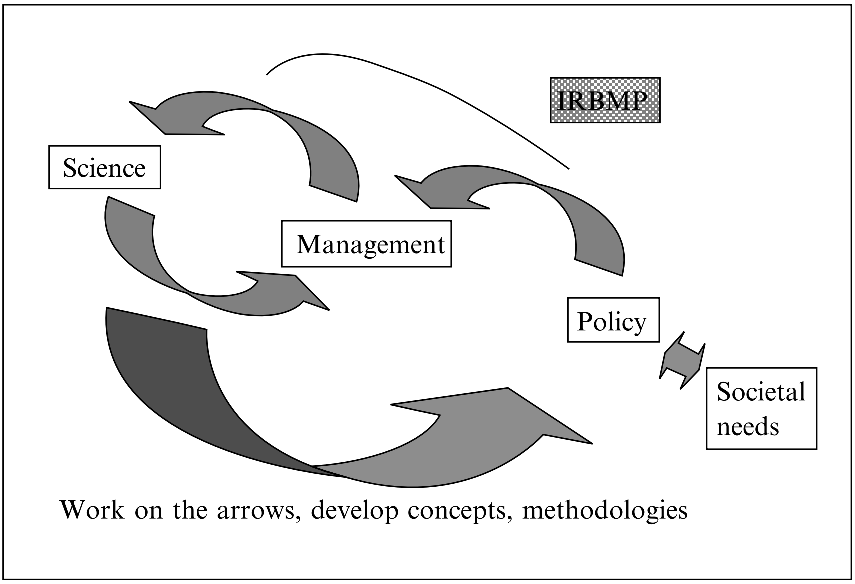

Figure 2. Objective of the IWM pilot study

3. Book Overview

The main goal of the book is to give a general framework about Integrated Water Management (IWM), that is the planning and management of water resources integrating the different issues involved (ecological, economic, technical, legislative, transboundary, etc.). The manuscript is the result of the research activity and the exchange of knowledge among a team of experts in different disciplines and institutions related to water resources, and includes both the different environmental problems that affect the very different ecosystems, and the main methodologies able to face the problem of IWM.

The book is divided in three parts: Concepts and approaches of IWM (Part I), Case studies (Part II), and Reports of the working groups (Part III).

In Part I, an overview of different methodologies and approaches for the planning and management of water resources is presented.

Specifically, the following approaches have been included:

- Approaches, based on DSS and GIS (Geographic Information Systems), that integrate different levels of information (that is, database, environmental modeling, and decision models mainly based on optimization);
- Partecipatory decision making processes (based on adaptive and collaborative approaches), which emphasize active public participation and social learning;
- Advanced ICT (Information and Communication Technologies) for data collection and interpretation, in order to suitably interpret and use huge amounts of data generated by systematic measurement. In particular, attention is focused on semi-automatic knowledge extraction from data and, more specifically, on Knowledge Discovery from Databases (KDD);
- Approaches based on transboundary issues and conflict management.

Part II includes different case studies that help the readers to get in touch with the real environmental/ecological problems related to IWM, and with the current organization for water management problems in the different environmental realities. The case studies have also the objective of applying the methodology discussed in Part I and/or of highlighting the need of managing water systems using an integrated methodological approach. A special feature of this book lies in the discussion of very different case studies that come from various parts of the world and that give, on the whole, a wide framework concerning water management approaches.

Specifically, the following environmental realities have been investigated:

- The Nete river basin (Flanders) management plan with specific attention to participation aspects;
- Transboundary management for the protection of Lake Constance (IGKB);
- Wetland habitats protection in the Upper Narew River System (Poland);
- Eco-hydrological issues for Turkey Creek Watershed, South Carolina;
- The management of Seven Cities Lake (Azores);
- Seawater intrusion in Cervia aquifer (Italy);
- Establishing the Iskar Reservoir (Bulgaria) Minimum Sanitary Storage Capacity (MSSC);
- Eutrophication in the Blackwater river catchment (Ireland);
- Water management in the Bouregreg basin (Morocco);

- Impact of Ignalina Nuclear Power Plant on the cooler-lake Drunksiai (Lithuania);
- Transboundary river contract Semois-Semoy between Belgium (Wallonia) and France;
- Ground and water levels change in the Scheldt Basin (France): transboundary issues within a multidisciplinary approach;
- Terceira Island (Azores) groundwater quality management;
- IWM plans for Greece;
- Transboundary river basin management in the Kaliningrad Oblast, South-Eastern Baltic;
- The role of the UNESCO HELP Programme.

Part III includes the discussion of different issues that emerged from the working groups organized during the meetings of the research group, as regards the environmental indicators for water resources management, and the participation processes in IWM. Specifically, the key issues that emerged as regards environmental indicators are for example: *which requirements are necessary to achieve health objectives, which diseases are acute, chronic, or recoverable, which are the parameters that must be measured, should be measured, could be measures in order to obtain different goals?*. Instead, for public participation, the main questions that must be solved are: How do we decide who should be involved? How do we involve the community (the ladder)? How do we ensure that everyone has the same information and same voice at the table?

Finally, the book contains a section of conclusions that includes discussion about the presented methodologies, approaches, and issues. In particular, the perspective of experts in different disciplines (engineering perspective, biology perspective, economic perspective, etc.) has been given and a wider philosophical and integrative point of view on water management reported.

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PART I

CONCEPTS AND APPROACHES OF INTEGRATED WATER MANAGEMENT

FILLING THE INFORMATION GAP BETWEEN WATER SYSTEMS AND DECISION MAKERS IN THE SUSTAINABLE DEVELOPMENT OF A TERRITORY

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Abstract. The path towards effective decisions on the integrated management of a water system requires a deep process of knowledge acquisition. System and information engineering can provide methodologies and tools to support the decisional process. In this chapter, a reference framework as regards the information processes to support decisions on water systems is formalized, with emphasis on: optimization where the management criteria to support decisions are formalized in a Decision Support System; and Geographic Information Systems where data and results can be viewed, processed and stored.

Keywords: Decision Support Systems, Geographic Information Systems, Integrated Water Management

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1. Introduction

Water management includes a wide set of related problems that should be jointly taken into account since they strictly interact with water demand, water availability, and water quality. The identification of sustainable pathways for proper land use development is a typical example. In this case, the main trade-off that takes the most problematic decisional aspects is between the anthropogenic actions and the conservation of natural resources. In this respect, the water system and its quality are also taken into account as one of the most important indicators for sustainable development, for example as regards the agriculture activities on a rural territory.

In fact, one of the main problems for an effective integrated sustainability assessment and development strategy definition on a basin territory is to fill the information gap between the knowledge of the state of a water system (also in connection with externalities coming from the state of other strictly related systems, such as, for example, a forest, a city, its economy, its population, its traffic, the related industrial district....) and the effects that a set of decisional alternatives, with the goal to select the most appropriate actions. This work aims to define the information model, which is based on a related information system, which should be used to manage the information flow and processing necessary to fill this gap.

Among the several system and information engineering approaches that are often applied to environmental systems, two of them seem of particular interest for water systems: decision support systems (DSS) and Geographic Information Systems (GIS).

DSS and GIS are two concepts that are very often twinned together in the management of an environmental and/or a territorial system. However, in a modern view, a comprehensive definition of a GIS should include a DSS (Malczewski, 1999) or, from another perspective, an environmental DSS (see Rizzoli and Young, 1997) should include GIS aspects. In this work, a GIS vision of the decision flow will be taken into account.

2. A Layered View of the Decision Process

A GIS, as many other modern information systems, is a complex collection of information processes allowed by a great number of hardware, software and communication technologies, with which the users, characterized by different competences and different objectives, can interact.

In addition, a GIS is the fundamental tool to define, model and implement many information/knowledge/decisional class of problems. The continuous growing of the anthropogenic actions on the territory, more and more needs an accurate monitoring action of the environment, in order to evaluate and plan the necessary interventions for the protection of the environmental quality and of the health of the population. In general, a GIS aims to fill the information gap between the status of the natural or anthropogenic environment (in a wide meaning of the term, such as, for example, a forest, a river, an expanse of sea, but also a city, its traffics or an industrial district) and a set of persons generally defined as "decision makers" who can select the most appropriate actions for the environmental protection.

A reference model is proposed hereinafter to sketch out the main characteristics to support decisions in the information flow from a water system towards decision makers. The architecture of this reference model can be structured in four layers: monitoring, database, GIS and models, decision support system layers. Each layer, which may be more or less distributed in a territorial context, can offer a reliable service to the higher layers. The link between adjacent layers should be guaranteed by adequate telematics communications.

2.1. THE WATER SYSTEM MONITORING LAYER

The first level, in a bottom-up order, can be defined as the "water system monitoring layer", whose task is to acquire information from the water system and the related territory in the form of "sustainability indicators". These indicators can be acquired by proper "sensors", in a broad sense, including in this definition: "sensors" monitoring natural aspects (for example, rain gauges, anemometers, hygrometers, cameras for map data acquisition placed on satellites, people collecting water samples and related water quality analysis processes) and "sensors" monitoring anthropogenic aspects (population, traffic, economy, industries etc...).

The service that is delivered by the water system monitoring layer is to provide a wide set of raw data to be stored in the database layer. The most innovative aspects concerning this layer is two folded. The first is related to the possibility to transmit at lower and lower cost a large amount of information from different remote, maybe moving, monitoring stations under wireless connections (see for example Vivoni and Camilli, 2002). The second is related to the enhancement of the sensor device, in order to get more data, and possibly in real-time. There is a progressive shift from traditional biochemical laboratory techniques, which are by definition "off-line", towards automated "real-time" technologies. The current research aim is to get cheap sensors, thickly displaced on the water system, reproducing the human senses to capture different widespread parameters. A part from traditional automatic visual and remote sensing techniques (see for example, Goddijn and White, 2006; Vignolo et al., 2006), electronic noses (see for example, Bastos and Magan, 2006; Goschnick et al., 2006), electronic tongues (see for example, Moreno et al., 2006), Doppler based techniques (see for example, Mossa, 2006; Brilly et al., 2006) have been developed and applied as concern monitoring of water systems. Another current trend is the use of nanotechnology techniques (Rickerbya and Morrison, 2007; Vaseashta et al., 2007).

2.2. THE DATABASE LAYER

The "database layer" represents the repository of the whole information related to the water system. Among the several methodological and technologic aspects that might be related to this level, two of them seem to be more relevant: the data model and the database feeding.

For the first aspect, the most frequently used data models are based on the relational paradigm. Data are stored in tables and the fields of different tables might be related to each other. From a design point of view, one of the fundamental steps is the design of the entity relationship schema. The data are often centralized, such as for example in the elaboration data processing centres of local or regional authorities which is responsible of the water system. In general, a common approach to data modelling in this layer is to define as much as possible a relational data architecture, including cartographic data, inserted in the so-called geospatial databases. In fact, leaving map and cartographic data to specific proprietary data models related to GIS software is still a common approach that is adopted. for efficiency reasons. From a content point of view, metadata, that are data about data, are an important, although controversial, aspect to be taken into account in database development. It is important since it allows to open the decision systems to other applications and/or to other decision systems. It is controversial since the decisions of the metadata standard to be adopted and the feeding of the metadata require time that is often taken into account as a deduction of time to the database design and implementation processes. As a matter of fact, metadata definition is a concrete fundamental process, and current research is also investing on this (see, for example, Peeter Nõges, 2004).

For the second aspect, database feeding, the gradual transition to automatic fed databases for water system management is currently undertaken, and new technologies are more and more used in this process. Database feeding is obviously strictly connected to the previous monitoring layer, and adequate communication protocols, and related standards, should be defined in order to allow the implementation of a database layer that is completely independent on the specific monitoring sensor, while it completely depend on the (standard) communication protocols that are used. XML schema may represent a valuable tool supporting these communication protocols (see, for example, Water Information System for Europe, 2007).

2.3. THE DATA ANALYSIS, SYNTHESIS AND PROCESSING LAYER

The third level can be defined as a “data analysis, synthesis and processing layer”, and it may be divided into two sub-components: the “modelling sub-layer” and the “GIS software sub-layer”.

In the modelling sub-layer, a mathematically formulated model, allowing to describe the behaviour of the water system at local and global scale is usually needed in order to predict the water system behaviour in terms of changing physical, chemical, biological, economic, demographic... conditions. The aim of these models is to model the water system behaviour under a complexity that depends on the characteristics of the decisions that are to be taken. The results of the models are usually stored in the database layer, either to predict future behaviours of the monitored territorial system, or structural changes, when new anthropogenic or environmental scenarios are supposed. Data that are necessary to the simulations to calibrate the system on the basis of historical data or to start calculations on the basis of real-time data are acquired from the previous database layer. As a matter of facts, the current techniques for numerical simulation of flow and/or water quality are highly specialized. The numerical techniques that can be used are very different and can be based for example on finite element, finite difference, boundary element and Eulerian–Lagrangian methods. The possibilities are so numerous and so different that recently even an ontology based knowledge management system for flow and water quality modelling has been proposed to “navigate” among the simulation alternatives in order to adopt the most adequate choice (Chau, 2007). In addition, in an integrated framework perspective, it is also necessary to model the interactions among the various subsystems that may be involved in the decisions. Figure 1 highlights an example of the subsystems to be taken into account and the connections (indicated by the arrows) among the various subsystems in a problem of sustainable development. To this end, it is necessary to consider different classes of problems that require separate modelling techniques (concerning both the physics of the system and the ecosystem): groundwater (aquifer pollution, seawater intrusion), surface water (rivers, lakes, reservoirs, estuaries) etc…

The second sub-layer is the specification of the required GIS allowing the graphic visualisation of the information contained in the database layer, giving relevance to the geographic characteristics of the data, while providing a user-friendly interface, which allows to show different information aspects (vegetation, logistic facilities, population density, rainfall data etc.) at a customable scale. Several computations can be performed and additional geographic information can be stored in the database layer.

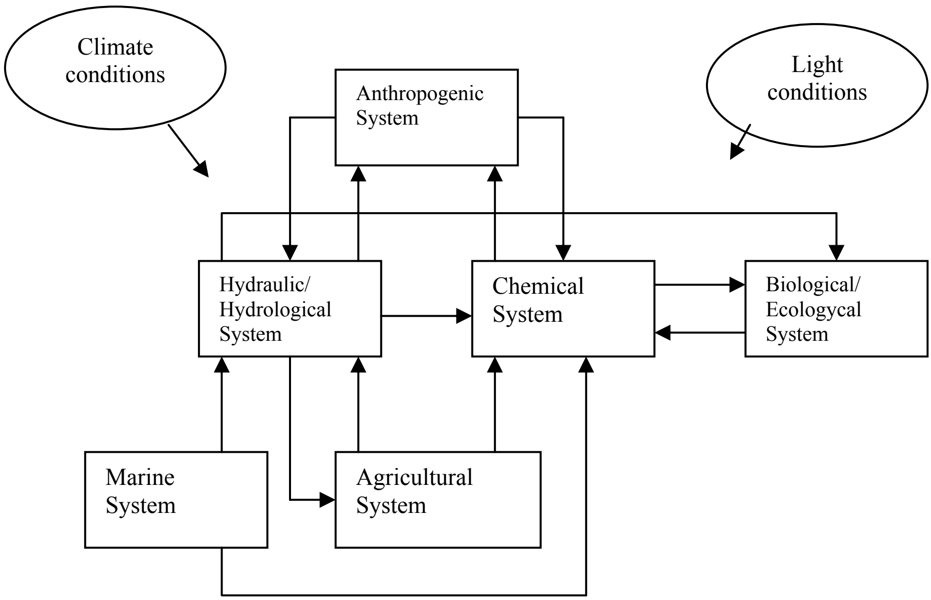

Figure 1. Subsystems for Integrated Water Management

Both the sub-layers, complementarily, can already provide to the decision maker an essential tool to synthesize the great amount of data collected and stored by the previous layers.

2.4. THE DECISION SUPPORT SYSTEM LAYER

Several authors underline the importance of information systems related to territory assessment as a decisional system (for example, Longley et al., 2001), and that the application of specific decision analysis techniques is more and more felt (Malczewski, 1999).

The definition of DSSs can be useful to identify strategies for the planning and the real time management of water resources (Minciardi et al., 2007; Lombardo et al., 2003; Minciardi et al., 2004). Specifically, the DSS layer may be based on the formalization of optimization problems (defining decision variables, objectives, and constraints) that can be solved through different techniques in connection with the complexity of the decision problem (mathematical programming, multicriteria analysis, dynamic programming, etc). Some important main difficulties regard the way how to use the physical model in order to state significant and computationally feasible optimisation problems, and in the selection of sensible temporal and spatial scales for the specific planning and/or management problem under concern.

Specifically, two kinds of decision problems are sought for IWM:

- *Planning problems*: a long term strategy aiming at the use of new technologies and the development of models capable of confronting future unexpected events;
- *Control problems*: a short/medium term strategy to improve the existing systems through the application of all available knowledge for the valorisation and conservation of water and soil resources.

Planning problems mainly regard decisions relevant to the choice of technologies, infrastructures, and to the definition of specific land uses. Such a kind of problems refers to long term decisions and their position does not need the use of real time information. Possible decisions that have to be considered within a planning framework are: where to install a pump (that is to say, the choice of the water body to exploit), which pump kind/size to use, how much money to allocate for specific tasks, where to install treatment plants (which size, kind, etc.), where to perform monitoring campaigns and networks.

Control problems regard those classes of decisions that should be taken by using also real time information. Specifically, examples of control decisions are: the definition of the pumping pattern, the definition of irrigation schedule, the application of fertilizers, crop rotation, plume containment for polluted aquifers. The first step is to identify the decision variables and to differentiate control and state variables. Control variables are those whose value is controlled directly by the decision maker, and that represent the way by which the overall system is driven by the external. Instead, state variables are used to represent the system behaviour over time.

The objectives of the decision problem represent the goals that are pursued by the planning and control strategies, according to the specific exigencies of the decision makers, while the constraints are necessary to represent limits to be respected, exigencies to be fulfilled, and can also be used to take into account the various issues of the problem (environmental, economic, legislative, social, etc.). The objectives and the constraints are formalized as a function of the decision variables.

Planning problems are either referred to an infinite time horizon, where decision variables are average values over time, or to a finite time horizon where final conditions are imposed to be the same as the initial ones.

Control problems are relevant to a transient behaviour of the system, and are formalized assuming that information about the system state is available in real time. State and control variables are assumed to have a dynamic behaviour in order to represent the system behaviour over time.

Different kinds of optimization problems, both in the planning and control problems, can be identified: single objective and multi criteria decision problems.

A typical example of a single objective problem is when only the minimization of one objective, i.e. the economic cost, is taken into account. However, since the IWM management problem concerns technical, economic, normative, and environmental aspects, several objectives can be taken into account. Multicriteria problems (MCDM-Multi-Criteria Decision Making) are classified as follows (J. Malczewski, 1999): Multiobjective decision problems and Multiattribute decision problems. The attributes are proprieties of the entities of the real world; measurable quantity or quality of a certain entity (decision objects). The objective is an indication regarding the system state that wants to be achieved (it indicates the directions of improvements of the attributes).

Often, the decisions are not taken by a single individual but from many decision makers. When there are many decision makers or decision groups, it is necessary to distinguish between a team and a coalition. The first one has consistent preferences, while, for the second, this may not be true. Besides, there might be two types of decisions: competitive and independent. Decision problems can then be referred or to easily predictable situations (deterministic, certainty situation: all information are known and there is a deterministic connection between decision and effect) or situations that are predictable in a very difficult way (uncertainty decision problem).

Among the approaches that can be useful in complex systems with different objectives and decision makers, the agent-based approach should be mentioned because of its promising applications also in the environmental field. Agent based approaches can be used in many applications.

Shen et al. (2006) report a detailed state of the art of their application in complex distributed manufacturing process planning and control, and highlight the importance of agent-based solutions in comparison with traditional approaches. Environmental applications can be found in different thematic areas, such as air pollution, land use management, natural risks management, etc. In particular, Wybo et al. (1998) refer to the application of software agents to the emergency management in command centers. As regards water management, an example is given by Feuillette et al. (2003) that describe a multi-agent model to negotiate water demand management on a free access water table. The model, developed for use as a research or experimental tool, is able to give an exact representation of reality and can thus be used for predictions, to understand the properties of interacting processes, to explore the dynamics of the system, and to test scenarios.

3. Conclusions

Water resources are a good that is essential for human life, activities, and for economics. In Italy, the consumption is about 210 liters/ day/inhabitant, without counting the consumption for industrials and agricultural uses. Evidently, water resources should be preserved and well managed, integrating all the different aspects of the problem (economic, environmental, legislative, technological issues). In the scientific community, great efforts have been spent in order to proper model the physical-chemical system related to water resources. These models are essential in order to represent the physical/chemical reality and to understand the possible effects of a certain strategy on the environment. Moreover, these models should integrate the ecosystem too.

There is a need for a common integrated approach to support the pathways that lead to decisions on the sustainable planning and management of water resources. Specifically, in a wide concept of GIS, attention should be focused on the definition of decision models able to integrate the modelling tools made available by hydrology, hydraulics, chemistry, etc. In particular, the main pressures on water quality should be represented in order to be used in the models for the planning and management of water resources: agricultural practices effects, aquifer over-exploitation, saltwater intrusion in coastal aquifers, point and diffuse sources of pollution.

In the literature, water and water quality models have been developed and applied mainly in order to build equations able to represent the physical processes related to water flow and transport of pollutants. On the counterpart, in a framework where DSS are proposed, a unifying approach is attained for the management of water resources, pointing that, as regards the modelling issue, there is the need of assembling, within a unified model, sub-models capable of taking into account different physical phenomena typical of agricultural, saltwater intrusion, mountain aquifers, etc.. By using such an integrated framework, it should be possible to formalize optimisation problems taking into account different aspects, like water distribution, agricultural practices and food production, environmental preservation, pollution control, depuration technologies. A main difficulty regards the way how to use the physical model in order to state significant and computationally feasible optimisation problems, and in the selection of sensible temporal and spatial scales for the specific planning and/or management problem under concern.

The use of ICT methodologies (efficiently applied in other themes of research such as manufacturing, traffic control, process control, etc.) in water management and water quality preservation is a challenging issue that can deeply help water managers in finding strategies that can take into account different issues. Advantages of such approaches can be helpful at different levels: efficient information exchange, help in physical/chemical models characterization, and definition and solution of optimization problems. This can take to propose strategies, to evaluate strategies, to accelerate decisional processes when new information is acquired at different spatial and temporal scales.

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TOWARDS AN ADAPTIVE APPROACH IN PLANNING AND MANAGEMENT PROCESS

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Abstract. Considering the complexity and the uncertainties of social and natural systems and the associated unpredictable events, it seems that the contemporary planning systems are no longer pertinent. We need to adopt ecosystem approaches which imply undertaking holistic planning and management that aim at the integration of natural and social sciences and traditional values. It is necessary to converge to adaptive and collaborative approaches which emphasise active public participation and social learning. All these considerations have implications on water management.

Keywords: approaches, adaptive, planning, management

1. Typology of Approaches to Planning

It is assumed that there are no isolated natural systems or social systems (Vitousek et al., 1997). Human beings are an integrated part of every natural ecosystem and there is a recursive and interconnecting influence among them with their interactions, interdependence and dynamics; one speaks of social-natural ecosystems and of integrated human ecosystems, where the human being is the main agent. The integrity of these ecosystems depends on the adaptive capacity of overcoming its vulnerable condition before shocks, i.e., depending on one's resilience and endurance capacities.

Considering this global human ecosystem, we have the perception of the coevolution of ecological and societal systems, and the complexity that emerge from these constant interdependences of physical, biological, economic, cultural and political phenomena. Consequently, we realize that nowadays there are

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relevant environmental and social problems that have a great complexity and a high degree of uncertainty.

What structure of thinking is capable of dealing with such complexity? The complex systems cannot be comprehended using the classic science perspective.

Funtowicz and Ravetz (1993) proposed the necessity to develop "a new scientific method, neither value-free nor ethically neutral" which is defined as Post-normal science, a new science for new times, a science with values. They consider that the essential function of quality assurance and critical assessment can no longer be performed only by a restricted corps of insiders (such as scientists and experts), the dialogue must be extended to all of those who have a stake in the issue, that is, to the extended peer community.

When the problem situation is well defined (system uncertainties and decision stakes are both low) then normal science (positivist and reductionist science) will work well, but when the problems are poorly defined and there are great uncertainties potentially involving many actors and interests, then we must attend to this new production of knowledge.

Dempster (1998) taking into consideration this typology of scientific focus, established the relationship between the models of processes of planning and the characteristics of the existing problem and recommended a similar diagram which pictures three zones focusing prescriptible planning (Fig. 1).

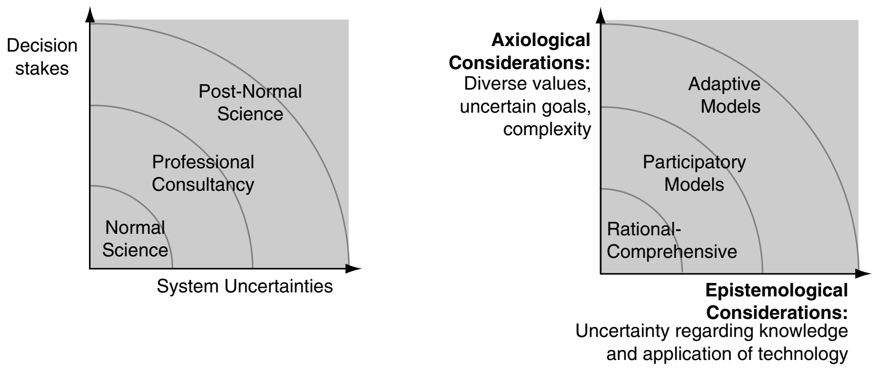

Figure 1. Typology of approaches to planning. Source: Funtowicz and Ravetz (1993) and Dempster (1998) (Reprinted with permission from Elsevier and Beth Dempster).

The x-axis represents different characteristics of situations of planning which appear and which focus two different types of uncertainty (values and knowledge). The resulting zones should be recognized as extensive categories freely defined.

This typology is useful to define the appropriate choice of planning before specific situations:

Zone 1: rational comprehensive model – This model is the most applicable where certainty is great (concerning the outstanding knowledge and technique of the planning situation) and where complexity is low (referring to values and aims); this model was developed recurring to experts.

Zone 2: participatory models – this zone includes a variety of focuses which stress the inclusion of relevant participants in the planning situation, recognizing the plural values; they encourage the participation of the stakeholders in taking decisions (including the most diverse interests and participants, then a greater ability in dealing with uncertainties occurs).

Zone 3: adaptive models – the extreme situations of this zone constitute the occurrence of a great uncertainty referring to the knowledge and to the application of technology or to the great diversity of values, uncertain aims and complexity; one of the basic ideas inherent to the adaptive management is to generate learning opportunities when embodying in the project phase, the experimentation, the monitorization and reassessment, which should necessarily involve planning; as a consequence, the distinction between planning and management (which is already in itself rather indistinct) becomes even more undefined in this sense.

Consequently all the complexity within the societal-natural ecosystems needs an organizational and leading culture which is completely different from the traditional ones, demanding empowerment, to achieve a structure which takes horizontal and inverted decisions, aiming at an adaptive organization based upon a learning process.

2. Adaptive Approach in Societal-Natural Ecosystems Management

Facing all the complexity and uncertainty inherent to the ecosystems, one advocates the need of an ecosystem and adaptive management.

The application of the ecosystem approach in the natural resource and environmental management will help to achieve a balance between conservation, sustainable use and equitable distribution of benefits. This emphasis is based upon the application of appropriate scientific methodologies focused on the different levels of ecological organization which include the essential structure, processes, functions and interactions between human beings and their environment.

Applying ecosystem management involves public collaboration, it relates people to “ecosystems” of which they are a part and it needs an organizational and leading culture which is completely different from the traditional ones, demanding empowerment, it achieves a structure which takes horizontal and inverted decisions, aiming at an adaptive organization based upon a learning process.

The concept of "adaptive management" was developed by ecologists to shelter the uncertainty, the complexity and the coming of unexpected happenings in the natural ecosystems, having appeared in the literature of natural resources and environmental management. It appeared as a type of application which enables learning through experience at the time of the implementation of politics of management of natural resources. It was then considered that in the most complex situations, where a high rate of uncertainty existed, a better effective use of the resources occurred, if adapting and learning were emphasized.

According to Lee (1993) adaptive management "is a synthesis of science and policy that treats policies as large-scale experiments. Bounded conflict (...) is a combination of politics, negotiation, and other means of promoting uncomfortable change, which provides tools for establishing shared goals and probing the bounds of co-operative effort. Like compass and gyroscope, the two parts of social learning are complementary".

However, recently, one has applied planning and adaptive management to a wider scope of scales, which vary according to the landscapes (big ecosystems at a regional scale), being defended by land use planners. In these contexts the ecological introspections of "traditional" adaptive management are combined with social learning and with the perspectives of the social institutions, so as to include important stakeholders, to balance the distribution of power among the stakeholders and endeavour towards processes of solving conflicts and find agreements.

There is no single way of implementing the ecosystem approach, as this depends on local, provincial, national, regional and global conditions.

James Kay and colleagues (University of Waterloo, Canada) developed an ecosystem approach characterised by flexibility in learning through change, integration of new science with values, and resilience through a diversity of innovative tools, methods, and perspectives. It can be used in adaptive management, monitoring and governance of socio-biophysical systems, which are Self-organizing Hierarchical Open (SOHO) Systems (Kay *et al*., 1999).

This model integrates the considerations of a variety of participants and stakeholders with scientific understanding (Fig. 2). The application of this approach involved the integration of the main components: the description of the ecosystem (by the scientists and experts) and the analysis of structural matters.

The analysis of the description of the human ecosystem is a scientific exercise to describe the relations between the biophysical and the social systems.

It allows the determination of holarquic perspectives which are relevant for the analysis, demonstrates the relations between the components, structures and processes and identifies the influences and feedback among the systems.

The structural question is designated to clearly define the problem, to determine the important questions and concerns and reveal the applied values in the elaboration of the decision and their judgements. The decisions which lead the elections and actions connected with the environment are in an inexplicable way rooted in the human concerns, which are influenced by the vision one has of the world and they are adopted by one's culture and values. These facts, in turn, determine the general vision of what one would like the world to be.

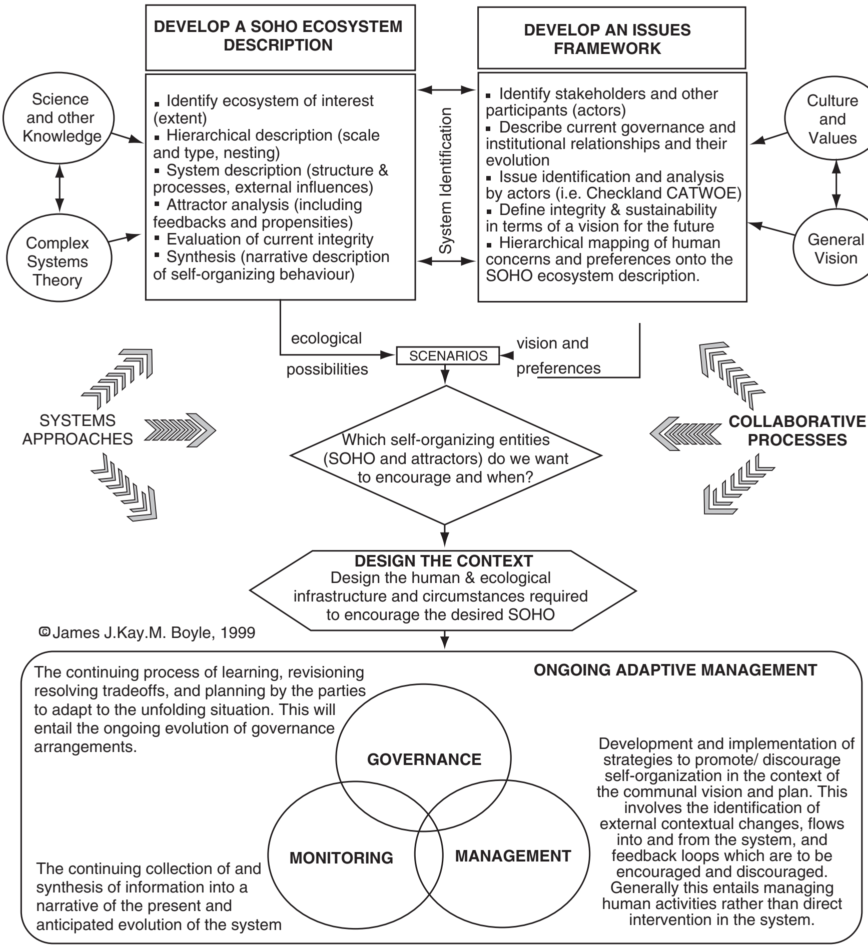

Figure 2. An ecosystem approach for sustainability: addressing the challenge of complexity Source: Kay et al. (1999) (Reprinted with permission from Elsevier and Michelle Boyle).

This is a kind of exercise which is based upon the foundation for a process, resulting from it a clear study of the vision and articulated preferences from the characteristics of the desirable result.

The structural matters ensure that the resolution is deeply rooted in the human interests and in specific aims, when considering the problem in question, i.e. people can project an ecosystem which is more favourable from the anthropocentric perspective, but it must take into account the existing ecological limitations specified by scientists in the description of the ecosystem.

So, it is important to determine the function of the participants and stakeholders in the process of decision taking, as well as their preferences in the final result. Several scenarios may be considered according to the values presented to solve the problem.

All the information that was collected about the system is summarized to contain the self-organizing behaviour of the system and to value its normal state.

Everything that is not identified as part of the description of the ecosystem is within the context.

To conduct the system one tries to understand the way the context (as a whole) influences the system in its whole. The analysis trusts the application of a traditional science, within the existing knowledge and the theory of the complex systems.

The adaptive management uses the tendencies of the natural system for the self-organization and uses the change to promote a system which keeps itself in an ample level. With an adaptive ecosystem approach management, strategies are outlined to support the system in the self-organization in the way one prefers In this process the scientists inform the way to take decisions which includes all stakeholders who are interested in the result, and the consulters are the ones who facilitate the process, those who help the client to obtain the best result, being the whole process centred in adapting and learning.

3. Towards Adaptive Water Management

The present perception that fresh water is a finite and vulnerable natural resource, that it is a social and an economic good and that it is inextricably linked with the global environment are demanding increasing attention.

The pressures facing the hydrological infrastructures system and water resources are the rapid growth of population and urban communities; changing land-use (as sitting of industrial plants; agricultural activities; deforestation; loss of catchments areas); changing land-management practices (pollution from human activities as the use of agrochemicals, discharges of industrial waste water); increasing demands of available resources (in general); and climate change (there are some uncertainties about this) will have impacts on groundwater recharge, water quality or flooding patterns. These changes in the cycling of water could have very significant impacts across many sectors of the economy, society and the environment.

Consequently there are increasing conflicts of use of water between different stakeholders' interests. In dry climate areas the needs of water are increasingly become an objective of military action or an instrument of war. There exist upstream and downstream conflicts over (scarce) water resources within watersheds (within states and between neighbour states); conflicts over abundance; conflicts of interests in water use: from irrigation communities, industrial enterprises, domestic use, all these actors have different objectives and resources; water without quality causes problems of public health risks; the scarcity or over abundance of water threatened ecosystems (in all space scales); and finally there exist conflicting visions for water management. We understand the complexity emerging from these constant interdependences of physical, biological, social and political aspects of water issues.

The exploration of water resource needs to be sustainable. Consequently it needs the attendance of ecological integrity of ecosystems, social equity and economic efficiency.

If a system is capable of keeping its organization before environmental changes, then it is said to have integrity (Kay, 1989). So, the exploration of water resource cannot destroy this capacity of organization.

In attendance to the environmental dimension of sustainability and according with Daly (1990) that means:

- its rates of use of renewable resources do not exceed their rates of regeneration;
- its rates of use of non-renewable resources (as fossil fresh water) do not exceed the rate at which substitutes are developed;
- its rates of pollution (inherent to irrigation, Industrial and power station cooling, navigation) do not exceed the assimilative capacity of the environment.

Thinking on the dimension of social sustainability we must attend that, the human right to water is fundamental to meet basic needs as United Nations Committee on Economic, Social and Cultural Rights determines in November of 2002. Communities must attend systematically to the principle of equitable use based on an upstream-downstream hydro-solidarity.

The need for economic efficiency requires the evaluation of the social and economic benefits and costs of different water uses. It is important to promote changes on patterns of consumption and production, to promote values of self-sufficiency and efficiency and to consider a more equitable access and distribution of natural resources (such as freshwater) but in a sustainable way.

We need a new culture of water which takes into account the sustainability of the resource when it comes to satisfying the human consumption needs in harmony with natural ecosystems integrity.

Considering water policies, in "developed" and developing countries the attending of supply-side adaptive options (water supply management) have dominated, approach that has been to develop new supplies and to construct structures to utilise available supplies to meet water needs.

Nowadays the attention to other ways of water management which lead to demand-side adaptive options (water demand management) is increasing. These options are focused on lowering or mitigating proposed demands in a more socially beneficial manner that rely on socio-economic techniques (like economic policies, water pricing, public education, recycling, laws, land use) and usually are not capital intensive structures. These kinds of options promote management of the water resources for sustainability.

A more holistic approach is needed because water systems should be understood and managed as living ecosystems, characterized by its great complexity and uncertain. This perspective attends to social, ecological, environmental and landscape values and needs an ecosystem management that allows to sustain or to restore the ecological integrity of affected ecosystems.

This new approach requires a continuous participation, capacity building and governance. The participation of the communities in this adaptive water management shows the necessity of distributing the social responsibility among the different actors and consequently of creating a contractual society and actions, so as to achieve consensus and establish agreements.

The concept of "adaptive capacity" is defined as the sum of social resources that are available within a society that can be mustered in order to effectively counter an increasing natural resource scarcity (Ohlsson, 1999).

Considering this new concept Turton (1999) distinguished two main components of adaptive capacity: the structural component comprises the sum of institutional capacity (including financial capacity) and intellectual capital which allows for the generation of alternative solutions such as water demand management strategies by technocratic elites; and the social component is defined as the willingness and ability of the social entity to accept the technocratic solutions (such as water demand management strategies) as being both reasonable and legitimate.

On the last decade, one has applied planning and adaptive management to river basins (Cortner and Moote, 1994). Conventional river basin water management has been strongly influenced by anthropocentric perspective of water resource which gives more emphasis to land use control, providing measures to protect water reserves and to reduce the risk of contamination. However, it has not always provided sufficient protection of water, as an ecological element. Ecosystems have limits to the amount of stress they can accommodate and their capacity of resilience and self-organization must be taking into account by water managers and stakeholders. In face of the associated complexity and uncertain, it requires an adaptive approach which demand learning by experimentation and a pro-active public participation.

The adaptive approach comes as a way to achieve sustainability and resilience of human ecosystem, providing solid principles to guide the integrated planning and management of the watersheds.

4. Final Considerations

The vision of sustainability is demanding ecosystem approaches (that take into consideration ecological and cultural integrity) and adaptive approaches (which depend of community management, social flexibility and learning), integrating the values and the perceptions of communities.

Consequently, water must be planned and managed in this holistic way, taking interactions among users and ecological needs and environmental impacts into account. This perspective requires integrated catchments management, demands governance and increase stakeholder participation. Effectively, this new approach requires a continuous participation and capacity building which converge to a collaborative and adaptive capacity that turn possible building up awareness, knowledge, skills and operational capabilities.

A reform in water management is required, and innovative societies are looked for, setting in motion a territorial organization that follows social, natural, cultural and ethical contracts in the election of land use models, in the design of key sectors like water, energy and transport.

It seems that actually the classic planning models have lost their utility and that land management is suffering a conceptual and instrumental transformation without precedent.

Adaptive model demand choices and trade-offs and the selection of these is driven by values through an active public participation which contribute to all process by the information gathering, analysis, decision-making, implementation and capacity-building, and monitoring and evaluation of projects.

This adaptive management will help to achieve a balance between water conservation, sustainable use and equitable distribution of benefits.

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THE VALUE OF THE ITALIAN CIVIL PROTECTION SYSTEM IN INTEGRATED WATER MANAGEMENT FOR THE MEDITERRANEAN ENVIRONMENT

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Abstract. In the Mediterranean environment, specific aspects related to integrated water management are emphasized: water scarcity (droughts) or water excess (floods). Water-induced disasters are increasing in number and severity and international institutional frameworks to reduce disasters are being strengthened under the United Nations oversight. Italy, as well as many other Mediterranean countries, invested a large sum of money in water-related risk mitigation. In this paper, flood mitigation actions focusing on different aspects of the problem (urban planning and warning, floods management) and on different levels (scientific, technical, political, social) are presented. Their possible transfer into a broader integrated water management (IWM) scheme is discussed. Techniques for environmental data gathering from different sources (multi-sensor retrieved data), models for hydrologic cycle simulation and systems for social awareness improvement are described. These experiences where supported by different expertises that can be highly beneficial to other aspects of IWM levels from local to regional level.

Keywords: integrated water management; early warning; natural hazards; disasters reduction

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1. Introduction

Human life, society and property are all essentially fragile elements, very susceptible to adverse pressures. Many traumas are caused by the environment we live in: to a greater or lesser degree, every natural human environment is fraught with hazards, i.e. "conditions capable of exerting adverse effects on human life, property or activity". Sometimes, and more frequently in some areas than in other, such hazards may become so acute that they cause disasters. In turn, disasters may be defined as "serious, damaging effects on human life, property or activity which may be the results of the impacts of hazards which have exceeded some critical level or levels" (Barrett et al., 1991, Roth et al., 1996).

Burton et al. (1978), in their classic work on The Environment as Hazard, suggested that 60 percent of the world's disasters are caused by hurricanes (causing the greatest number of casualties) and floods (the most frequent causes of disasters). Both hazards and disasters are not only of many different kinds, but are also varied in respect of the type of observations that are required to identify and evaluate them. In the case of hazards, frequent - even continuous - monitoring may be required to identify those areas and periods when certain circumstances "go critical". On the other hand, the disasters that may then result - because these tend to be more localised in space and time - often call for highly focused observations (Roth et al., 1996; Rudari et al., 2004). In recent years there has been a growing appreciation of the degree to which moderate to high-intensity precipitation events constitute - either directly or indirectly - potentially serious environmental hazards in many areas of southern and western Europe. These can be particularly serious over "flashy" basins (common where slopes are steep, as in many areas of southern Europe), and/or areas where the existing soil moisture content is already high. Large urban areas can also increase the effects of heavy precipitation events, due to the large amount of impervious area.

Monitoring tools and simulation techniques which are developed for - and thus provide information at - different spatial and temporal scales need to be properly integrated when the use of remote sensing in flood forecasting is invoked. Within this framework a series of problems arise in the determination of both suitable validation techniques, and cross-fertilising procedures able to allow for a wider use of remote sensing tools in monitoring and forecasting environmental variables.

Integrated multisensor systems afford some promise of joining different monitoring and interpretation techniques into a unique operational procedure. This procedure should be able to complement the perception of analized/modelled variables at large scale together with the assessment of their small scale variability.

On the other side, effective systems for early warning against natural hazards should include, beside the scientific and technical basis, also a strong focus on the people exposed to risk. Similarly, a system approach that incorporates all of the relevant factors, arising from the natural hazards or social vulnerabilities, and from short-term or long-term processes, is needed. Therefore, in many countries Civil Protection has put a lot of effort in empowering the social awareness because population should live aware of hazards pending on certain part of the territory. This is fundamental in many IWM activities, where the population can be considered one of the stakeholders.

In this paper, all components of an efficient flood warning system are described according to the recent Italianan legislation that insituted the National network of "Centri Funzionali". In this context, different arguments are discussed in detail and taken as paradigm for integrated water resources problems at large. First, monitoring precipitation from different sources is discussed as an example of how environmental variables are difficult to observe and analyze in real-time, then hydrologic modelling is presented with its new trends and capabilities, and, lastly, social response is analyzed.

2. Environmental Data Gathering for Flood Forecasting

The knowledge of precipitation and its underlying processes is required in a number of research and application disciplines related to the global energy and water cycle. This includes climate, meteorology, hydrology, oceanography, transportation, agro-meteorology, numerical weather prediction, nowcasting flood forecasting, and, with its comprehensive aspects, the integrated water resources management. Moreover, these research areas are expected to have a growing socio-economic impact in the future, following societal adaptation to climate change. In the following, the related increase in precipitation observation capabilities, with the associated benefits in reducing the impact of hazardous storms on human activities, will be discussed as it constitutes a paradigm also for other research and application disciplines as well as other environmental observations.

The development of methodologies for meteorological data interpretation, validation and integration, based on multisensor data sources of varying spatial and temporal scales is a viable way to approach the problem of precipitation measurement and forecast. A variety of data sources can be employed including quantitative precipitation forecasts, polar and geostationary satellite, meteorological radar and rain gauge network information. These can be used to aid in the estimation of precipitation intensity and areal coverage and its ground effects, and to provide early warnings of flood hazards to communities that could be affected by such occurrences. A brief description of the main characteristics of the sensors is provided below, in technical and operational terms.

2.1. MULTI-SENSOR DATA OBSERVATION

2.1.1. *Geostationary satellite observations*

The use of infrared imagery obtained from meteorological geostationary satellites has received increasing attention from the European scientific community since the operational mission of the ESA-Meteosat Programme (Mason, 1981). Images are characterised by a quite low spatial resolution (3 km in mid-latitudes) and a quite high temporal resolution (15 minutes) when compared with the usual scale of evolution of meteorological processes developing at the synoptic scale. Quasi real time acquisition and interpretation of data are possible on the basis of empirical algorithms which allow translation of information recorded by on-board sensors into average precipitation intensities over large areas. The cost of data acquisition is quite low due to the stationary orbits, permitting the use of fixed data collection antennae.

2.1.2. *Polar satellite observations*

Microwave sensors on polar orbiting platforms (e.g., Spatial Sensor Microwave Imager, SSM/I) provide images with lower spatial resolutions (≈15 km). Moreover, there is also low resolution in time due to the low orbiting overpasses (once or twice a day over the same location). However, in this case the information obtained from the sensor is much more linked to the inner microphysics of the clouds when compared with that obtained by infrared sensors. Passive microwave data are only available for real-time operational use in some centres, and for restricted areas of the globe.

2.1.3. *Meteorological radar observations*

Meteorological radar maps present the enhanced spatial (up to few hundreds meters) and temporal (up to few minutes) resolutions needed for flood forecasting applications; real time acquisition and processing of data can be crucial in the face of the issuing of meteorological warnings. Although radar accuracy of precipitation estimation depends on several factors, as sensor calibration and characteristics of both the precipitation event and monitored area, recent multiparametric radar techniques allow, if combined with a rain gauge monitoring network for the calibration, quite accurate precipitation estimates (Giannoni et al., 2003). Unfortunately, low predictive capabilities often result from the limited spatial coverage associated with a single radar. Moreover, the use of meteorological radar installations is often constrained by high installation and management costs, and a full coverage of the land areas of the world is not in sight.

2.1.4. *Telemetered rain gauge network information*

Traditional rain gauges provide point information over a range of time scales. The real time acquisition and interpretation of such data can be achieved by means of telemetering networks and simple algorithms. The information from the rain gauges is sometimes referred to as "ground truth" precipitation but, even this, is liable to error. The weak points include the following: estimation of precipitation is possible only after it occurs and predictions rely on statistical extrapolations and analyses of long time series: the variance of this point random process makes the latter unsuitable for predictive purposes when short time interval and long lag times are concerned; the predictive content of the information is low due to the unreliability of the spatial extrapolation of point data from few observations and for short prediction time intervals. Relatively low installation and management costs encourage the spreading of rain gauge networks for monitoring purposes over much of the world's land areas; however little or no coverage is available over the sea areas, from which most of the storms come which affect coastal areas.

2.2. INTEGRATION TECHNIQUES

The aim of integrating multisensor information is the optimal identification of meteorological scenarios which are apt to develop intense rain cells and the tracking and forecasting of the evolution of the related cloud system. To this end, some major issues should be taken into account: the indirect nature of remotely sensed precipitation measurements; the ratio between the spatial coverage of a single sensor and the spatial resolution of the derived information; the available temporal resolution of the measurements. From the brief description of the different sensors given in the previous sections, it is easy to identify a lack of relatively accurate and reliable knowledge of the precipitation distribution at small spatial ($1-10\ km^2$) and temporal (10 minutes) scales unless radar data are available, which is still quite rare.

2.2.1. *Rain-rate assessment from synoptic weather maps and remote sensed data*

The synoptic-scale pattern and weather-forcing can be studied by using objective techniques (Rudari et al., 2005). Composite maps delineating the area covered by quasi-geostrophic forcing, potential instability, water vapour convergence, and strong Convective Available Potential Energy (CAPE), seem to be an effective tool to identify the areas where mesoscale focusing mechanisms become effective. It is important to stress the contribution of remote sensors in supporting traditional monitoring devices to improve diagnosis methodologies at the synoptic scale. The use of remotely sensed information and conventional meteorological data sets makes easy to identify the areas where the main localisation and triggering of precipitation cells take place. However, sometimes the general pattern does not justify enough the presence of such strong convective activity and heavy precipitations. It is therefore necessary to look for sub-synoptic mechanisms that could localise and trigger convection; for this reason, a detailed mesoscale analysis is frequently used.

2.2.2. *Rain-rate assessment from Meteosat and polar satellite images*

Simultaneous microwave and thermal infrared passive measurements from satellite platforms can produce complementary information on cloud and precipitation systems. The upwelling radiation measured by microwave radiometers aboard polar-orbiting satellites is directly responsive to precipitation microphysics. Meanwhile, thermal infrared radiation measured by sensors on board geostationary and polar-orbiting satellites is strictly correlated to cloud top structures and not necessarily to the underlying layers. *Vice versa*, space and time scales of precipitation are not properly addressed by microwave radiometers, while infrared sensors on geostationary satellites perform considerably better. In view of the above the space and time resolution of the SSM/I radiometers pose serious limitations to their potential for operational flood hazard forecasting. This problem would be alleviated by resorting to a network of space-based microwave radiometers.

2.2.3. *Rain-rate assessment from Meteosat images and rain gauge data*

To develop a methodology to integrate the information coming from these two different sources, static integration procedure can be developed. These procedures usually estimate a precipitation pattern associated with a fixed time interval. Based on the sequence of such estimated precipitation patterns, and on the use of a dynamic rainfall/runoff model of the basin, an estimate of the hydrograph at some given sections of the river can then be generated. The integration procedure is essentially based on the statement and the solution, by means of mathematical programming techniques, of a data coherence problem of a quite general structure. The behaviour of the procedure has to be tuned by choosing the appropriate values of a set of parameters. Such tuning should be necessary only to adapt the procedure to a specific basin area and to a specific storm morphology.

2.2.4. *Rain-rate assessment from radar and rain gauge data*

In an operational monitoring or forecasting system, the fine-tuning and integration of radar and rain gauge data must be at least a semi-automated process. Before any attempt at routine integration is made, it is imperative to analyse in detail events where radar and rain gauge data are both available, to assess which rain gauges are best suited for comparison purposes. A particular problem, of course, is the effect of terrain on the radar data, which can increase or reduce precipitation estimates, depending on the relative positions of the radar beam, the interfering terrain and the rain.

3. Models for Hydrological Simulation

The prediction of the hydrologic response of a river basin is fundamental in hydrology. This includes the description of the dynamics of several processes, from rainfall to runoff through soil and vegetation response to precipitation. Within the context of flood forecast and prevention, a large number of lumped and distributed models were proposed to explain, at the basin scale, the flood formation process and its relation to the rainfall input. Nowadays, different sources of environmental information are available in real-time, or near real-time such as the ones described for precipitation in the previous section, at reasonable cost in a spatially distributed manner. In the last decade, this sped up the advances in distributed hydrologic modeling, which eventually resulted in a better understanding and representation of both runoff formation and propagation dynamics (Wood et al., 1988, 1990; Winchell et al., 1998). Distributed modeling allows us to describe the role that is played by space and time rainfall distribution (Giannoni, 2003), by soil and vegetation heterogeneity, and by the drainage network structure (Downer et al., 2002; Giannoni et al., 2000, 2005). Therefore, the use of models capable to exploit distributed information has consolidated in flood forecasting, notwithstanding that a distributed description of the processes involves a large number of parameters as well as the associated problem of reliably estimating them (Beven, 1989; 1993).

When dealing with flash flood forecasting there is always the need of combining divergent requirements. A model that is to be implemented in a flood forecasting context needs to be portable and robust, because many of the catchments where the model is applied are un-gauged, and computationally fast, as it is nowadays obsolete to deal with flood forecast in a deterministic way so that a large ensemble of model runs is usually needed to deliver a usable forecast product (Rudari, 2003; Siccardi et al., 2005).

The need for simple schematizations led in the past to the large implementation of partial hydrological models working at the event scale, using simplified schemes for rainfall abstraction. Although event models have been successfully employed in this field, nowadays their value, which resides in their simplicity and robustness, is more and more confined to prediction problems. Forecasting problems call now for continuous, or continuous-like models, because of their ability in estimating initial conditions (e.g., soil moisture distribution) to be used in the forecast. In fact, the common belief that for flash floods the influence on peak discharge of initial moisture conditions is poor, flaws when the performance of a forecasting chain is evaluated in a long period and not on the basis of few extreme case studies.The added value of flood modeling resides in its ability to discriminate ambiguous cases. For these reasons soil moisture as well as the evaluation of many other fundamental state variables has become one of the main focuses of hydrological modeling leading to more complete and representative models.

All these considerations, together with the availability of inexpensive computational power has led the hydrological community to work on models that, thanks to their distributed nature and complete description of the processes, can be profitably employed to study different aspects of the hydrological cycle. For example, an optimal representation of soil moisture is fundamental in many practical problems. Soil moisture is a key variable in the water and energy balance processes determining the partitioning among ground heat flux, latent and sensible heat. Moreover it influences directly the separation between surface runoff, soil infiltration and, eventually, groundwater recharge.

In this framework models that are developed for flood prevention purposes can now be employed with little adjustment in water scarcity problems and vice versa. In this way, many modelers devoted to specific problems can benefit of the experience of colleagues skilled in different fields.

Within this panorama it is important to recognize where different modellers in different fields acquired more expertise due the distinctive nature of the problems they were trying to solve. In the following we will try to underline some important aspects regarding the experience obtained by flood forecasting modellers, although some of these aspects have been already mentioned in order to clarify the purpose of this section.

One of the peculiarities of models dealing with Flood Forecasting (FF) is their need of data not only from historical series (i.e., for calibration), but, especially, in real time. It is in fact common that traditional data are scarce in their temporal history (e.g., for stream flow measurements) or poor in their spatial description (e.g., for rainfall fields). These limitation push forward the use of diverse sources of data measuring the same quantity from a different perspective, as for rainfall when described by meteorological radars, or measuring other quantities (e.g., Land Surface Temperature from various satellites) thanks to the increasing number of state variables represented in models as a natural consequence of their development described at the beginning of this section.

An up-to-date model for FF is linked to a geo-database that gathers data from sensors of different nature in real-time or near-real-time. The model is therefore able to exploit these pieces of information to properly update the initial conditions for the simulation that normally is based on a forecast provided by meteorological models. In addition to that, data are used to adjust the values of the equation parameters, which are partly re-calibrated in real-time. This structure can be usefully employed in many application when a complex IWM problem is faced. The timely forecast of different state variables provided by this framework is in fact fundamental especially if, unlikely in flood forecast, some control can be exerted on the system. The need for using data as early as they are estimated by FF models could help to extend the lead time of forecasts and, therefore, lead to a more efficient intervention on the system or even increase the number of interventions in different parts of the system.

Models for FF, as many others applications, are implemented in order to support political decisions such as the issuing of warnings. Flood warning is extremely affected by the “crying wolf” phenomenon that decrease its efficiency when a large number of false alarm is issued. This aspect, together with the uncertain nature of the forecasts produced by models, forced modellers to develop a special sensitivity towards the quantification of prediction uncertainties and the problem of properly conveying the uncertainty associated with the forecast to decision makers and stakeholders. Lately, this aspect acquired major scientific attention and scientists devoted their research to carefully separate out, analyze, reduce (when possible) and, eventually, quantify the different sources of uncertainty (Ferraris et al., 2002). Within this context, ensemble systems supported by Bayesian techniques have been re-interpreted and adjusted to the new nature of models and their complexity as well as to the availability of new sources of data. The quantification of uncertainty is fundamental in many decision problems and many fields of IWM could benefit by critically analysing the way FF models are driven and their results are post-processed within a probabilistic framework.

The last aspect is strictly connected with the fact that in FF hydrologists are often forced to use as input of their models future realization of variables from meteorological forecasts (e.g., precipitation fields, radiation fields, etc.). This is necessary in order to gain enough lead time in forecasts. The time between the beginning of the event and the possible consequent land effects is often too short to put in action efficient precautionary measures unless the social system is already allerted. The need of interfacing with meteorological models forced the hydrologic community to exchange experience with meteorologists and eventually led to develop techniques to interpret and transform meteorological forecasts in order to be used by hydrologic models. The result is a mutual advantage for the two scientific communities and a deeper understanding of both meteorological and hydrological models strengths and weaknesses. This experience, which is common in dealing with interdisciplinary problems as IWM can facilitate the communication between modellers and other communities (scientific or political) dealing with complex problems. The coexistence of different modelling communities is one of the forces that drove the implementation of the system for decision support in civil protection described in the next section.

4. Systems for Social Awareness Improvement

To be effective and complete, an early warning system needs to comprise four interacting elements (ISDR-PPEW 2005 a): (i) risk knowledge, (ii) monitoring and warning service, (iii) dissemination and communication and (iv) response capability.

In order to sustain these four elements over the long run, it is necessary to have strong political commitment and durable institutional capacities, which in turn depend on public awareness and an appreciation of the benefits of effective warning systems. Public awareness and support is often high immediately after a major disaster event. Such moments can be capitalized on to strengthen and secure the sustainability of early warning systems.

As mentioned before, experience has shown that technically high-quality predictions by themselves are insufficient to achieve the desired reduction in losses and impacts to be effective. Dissemination, that is the last link of the chain, and response capability of the population are fundamental for the efficiency of the civil protection system. The human factor in early warning systems is very significant (Twigg, 2002). In this context, Italy has developed a very distinctive experience setting up a network of technical centres to maximize the efficiency of the alert system. In these centres, information derived by the analysis of different models and by monitoring networks are gathered to support the political and decision making level at best in issuing warnings and conveying information to the population in normal and emergency conditions.

This experience could be exploited in other frameworks, where distributed data management and dissemination to stakeholders is crucial.

In the recent past, many Italian regions were affected by natural catastrophes caused by extreme rainfall events. These facts led to put much attention to the prediction and the alert systems to avoid or, at least, to reduce the occurrences of this type of catastrophes. Therefore, several laws have been issued to face the situation. First is the National Law 225/1992, that institutes the National Service of Civil Protection with the aim of safeguarding human being, personal properties, settlements and environment from natural catastrophes and other destroying events. It establishes that Civil Protection has to issue forecasts, to carry out prevention activities and to aid people during the emergency situations.

The Law 267/1998 started a very ambitious project at national level, that is to develop a system called "Sistema nazionale di Centri Funzionali (CF)". The project is targeted to the defence from hydrogeologic catastrophes and their mitigation. The original idea of the CF network was to create a coordinated network for the real-time exchange of data and information (forecasts and observations) needed to guarantee an efficient meteo-hydrological monitoring and warning system all over the country for the assistance to the political decision making level in issuing warnings and alerts.

In the period between 1998 and 2004 a lot of work was done to improve the CF network, including the last important act that is the DPCM[1] February, 27th 2004. This Directive gives operational instructions regarding the management of the national distributed alert system based on the CF network. In this context, emergency situations are faced through different phases: risk definition, prediction, dissemination and emergency management. Now 22 CF exist nationwide: 21 regional centres and the National center (Fig. 1).

A CF, as already mentioned, is a technical and scientific centre that manages, checks the quality and interprets all the environmental data available from ground point sensors (e.g., rain gauges), ground remote sensors (e.g., radar) and satellite platforms (e.g., meteosat) to properly identify scenarios which can effect goods and population in certain part of the territory. These scenarios must be interpretable at non-technical political levels that are in charge of the dissemination and communication to the people.

In this perspective, a CF needs specific equipment in terms of people, technology and machinery. According to the Directive each operational CF includes three functional areas: one in charge of meteo-hydrological analysis, one in charge of data acquiring, validation and storing, and the last area devoted to maintain, update and reapair machinery, hardware and software

[1] Direttiva del Presidente del Consiglio dei Ministri - Directive of the Prime Minister, shortened with DPCM.

Figure 1. Representation of the CF network, each star represents a CF

appareil, also in critical situations. From the point of view of the machinery installation each centre has to put particular attention to data acquisition, validation and archiving. In fact, a CF manages in real time a big amount of data, a lot of which present a frequent update and needs to be efficiently visualized and used to update model runs. In emergency situation a CF is in charge of continuous monitoring and nowcasting the event under development. Nowcasting is the activity necessary to forecast and monitor the very near future allowing for the best dislocation of police, firemen and volunteer teams on the territory.

In order to be efficient, the scenario description should include all the possible land effects which will be a consequence of the event under analysis, together with the respective probability of realization. If this quantification is done properly, the political level has the best tool to act on a warned population in order to minimize possible damages. Obviously comunications in emergency situation are effective only if the recipients are used with such comunications and are already taught how to behave in critic situations. Therefore, the activity of information and rules of behaviour disseminated during ordinary conditions to the population is of extreme importance.

To facilitate the warning communication, Italy has been organized into Alert Zones that are portions of the territory considered hydrogeologically homogeneous, i.e. characterised by similar response to extreme events. The zones were defined considering local climate, geomorphologic and hydrogeologic characteristics, as well as the administrative boundaries. Figure 2 shows an example of the Alert Zone identified for the Liguria region.

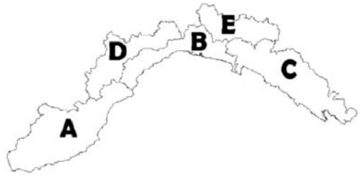

Figure 2. Example of alert zones: Liguria region

The CF network operates at the national level, consisting of regional centres distributed nationwide, allows capillarity monitoring with high performance-standard. Every day the National CF issues a *National Surveillance Bulletin* and when needed a *Criticity Bulletin* merging the National meteo-hydrological forecasts and observed data with the information contained in the regional bulletins. Ordinary conditions and emergency conditions are defined as follows.

4.1. ORDINARY SERVICE CONDITIONS

During ordinary service conditions (i.e., no risk situation is forecasted), a *Meteorological Bulletin* is issued daily, and the meteorological forecasts are used to drive the hydrological models. During the day in business-hours quality data check and weather surveillance is guaranteed.

4.2. RISK CONDITIONS

When a potential meteorological risk is foreseen, a predefined technical procedure is activated. Meteorologists and hydrologists of the CF join in an Alert Team. The Alert Team evaluates a potentially critical nature tof the current situation, analysing model forecasts and precipitation distribution. A briefing with an adjoining regional sąsiedni? CFs and the National CF is performed to prepare the decision phase. A meteo-hydrologic integrated forecasting chain is run in order to issue a *Hydrologic Bulletin* reporting the hydrological situation, the forecasted land effects together with an evaluation of the reliability of the results. According to the hydrologic bulletin, the Regional Civil Protection issues, if necessary, an *Alert Bulletin*.

There are three possible alert levels: ordinary criticity (due to lumped thunderstorms), moderate risk conditions (ALERT 1st Level) and high risk conditions (ALERT 2nd Level). The meaning of 1st and 2nd level of alert is here briefly described:

- ALERT 1st Level: the meteorological forecasted event determines a hydrologic scenario of FLOODS in both urban and suburban areas; LOCAL FLOODS that can possibly break banks and cause LOCAL LANDSLIDES. A threat for people and things is moderate.

- ALERT 2nd Level: the meteorological forecasted event determines a hydrologic scenario of high hydraulic levels that can cause FLOOD of cities, BREAK OF BANKS, OVERCOMING OF BRIDGES and FOOT-BRIDGES, DIFFUSE AND WIDE LANDSLIDES. The danger for people and things is high.

The last part of this complex system is notifying people of the forecasted weather conditions and the consequent land effects and possible critical conditions. In order to instruct people how to behave in critical situations, each Regional Civil Protection/or lower level department service sends information on “measures for self protection in case of floods”. This kind of information propagation has been disseminating to people for the last 6-8 years.

The Regional Civil Protection Department issues alert bulletins through different means. The Bureau of Major, Provinces and other Goverment Territorial Bureaux are informed daily via fax. Ordinary people are informed via mass media (newspapers, television news, etc.), through messages displayed on electronic boards located in various part of the city and via Internet. It has been proved that information available via web are particularly appreciated, in this option traffic-light map representation (Fig. 3) is an important tool. This map is public domain and can be found on the web-site http://www.meteoliguria.it/protezione-civile/index.html. In this map the colours correspond to the different levels of alert conditions in each Alert zone, as described before.

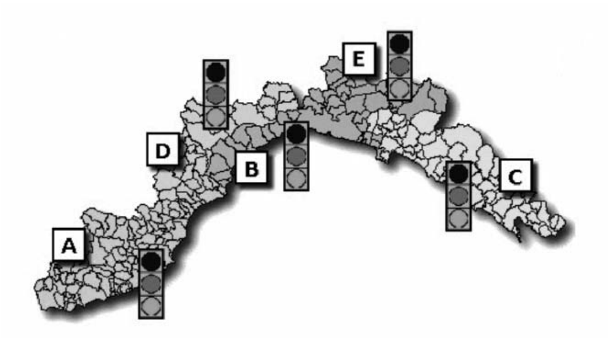

Figure 3. Traffic-light map over the Alert Zones in Liguria Region: green indicates NO ALERT, orange indicates ALERT 1, red indicates ALERT 2. Courtesy of Ligurian regional Civil Protection

When alert is declared, people and public organizations have to act according to the instructions received. Every Municipality has to follow the instructions contained in the Municipal Emergency Plan regarding the measures to take during a risk situation. The Mayor is responsible for his Municipality. He has to manage the local resources of Civil Protection, as suggested by the Emergency

Plan, according to the alert level. On the other hand, populationhave to activate self-protection measures in order to protect their own lives and personal goods.

5. Conclusions

The knowledge of water availability and its space-time distribution is required in a number of research and application disciplines. Besides, aspects related to water quantity and quality are expected to have an increasing impact in the near future, leading adaptation to climate change. An integrated approach to water management, with its comprehensive view, seems the way to overcome different approaches to the study of water related environmental processes, as they are nowadays proposed by different disciplines. In this framework, the identification of a common ground would be highly beneficial. A possible new starting points should be identified in monitoring systems, numerical simulation techniques, and decisional processes.

From this viewpoint, monitoring systems need to be properly integrated when the use of remote sensing for integrated water management is invoked. A series of problems will then arise in the determination of both suitable validation techniques, and cross-fertilising procedures able to allow for a wider use of such tools in monitoring environmental variables. In flood forecasting, integrated multi-sensor systems face some promise of joining different monitoring resolutions and different interpretation techniques into operational procedures.

Numerical models for water management, including those for flood forecasting, are more and more capableof describing every component of the water cycle, indicating the possibility of developing complete models useful for multisciplinary applications related to water. Their ability assimilating data from different sources increases their predictive skill on one side and demands, on the other side, for more specialization and flexibility of users and developers, who are requested to have diverse backgrounds. The trend of quantifying models results reliability smooths the possibility of using models results in decision support systems or simply in decision procedures which are common in integrated water management problems.

Technically, high-quality predictions by themselves are insufficient to achieve the desired reduction in losses and impacts. Dissemination and response capability of the population are fundamental for the efficiency of the civil protection system. Obviously, comunication in emergency situations are effective only if the recipients are used tothem and have been already instructed how to behave. Therefore, the activity of information and rules of behaviour disseminated during ordinary conditions to the population is of extreme importance. The increasing complexity of the messages produced by the technical level need to be effecltively translated and conveyed to decision makers and stakeholders, who, as happens in case of floods, are the main actors in reducing damages and losses.

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KNOWLEDGE DISCOVERY IN ENVIRONMENTAL DATA

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Abstract. An approach to tackling management problems of water resources is the introduction of the advanced ICTs (Information and Communication Technologies). In IWM (Integrated Water Management) and, in general, in the environmental field the power of these technologies has allowed for large-scale data collection campaigns. The number of parameters that must be measured to monitor an ecosystem is potentially high. Systematic measurement of those parameters generates huge amounts of data that should be suitably interpreted and used. A pragmatic approach has to be used to get the best information = knowledge from all this data. Within such amounts of data there is a lot of hidden information, in terms of models, patterns and trends. But information is difficult to be extracted since data is of varying quantity and quality. As a consequence, semi-automatic knowledge extraction from data has gained great importance within the economic and scientific community. Knowledge Discovery from Databases (KDD) has emerged as a framework where a plethora of techniques for identifying useful and understandable patterns in data have flourished. Most of those techniques can be used with success in the environmental field and, in particular, in IWM. In this paper we give an overview of what KDD is and mention some applications in these areas.

Keywords: Integrated Water Management, Data Mining, Environmental Databases

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1. Motivation: Overwhelming Amounts of Data!

According to the guidelines for the implementation of the EU Water Framework Directive, WFD, (Annex V), the list of water quality elements contains biological (priority), hydromorphological (supporting) and physico-chemical (supporting) parameters. The Directives give recommendations on the parameters that must be measured, especially on priority substances and "relevant" substances, for instance, such as the substances in List 1 of Directive 76/464EEC and List 2 of priority substances according to Article 16 of WFD. Obviously the number of parameters that must be measured is potentially high and that is why a pragmatic approach has to be used when the parameters to be measured are selected (Lavkulich, 2004). Systematic measurement of all those parameters will generate huge amounts of data that under the favourable hypothesis of being well organized will produce databases of considerable size that will have to be suitably digested and interpreted if their content is to be useful.

This is only one example of what happens in many companies, industries and research groups in almost any field. Large amounts of data are nowadays available because gathering data is easy and usually inexpensive. As environmental concern grows and information technology develops, more and more data on many different aspects (physical, chemical, biological…) of the environment are gathered. Environmental monitoring is an important source of data. Typically, samples are taken from air, soil, water and analyzed for their properties. Then, laboratory tests designed to estimate the influence of some substances on the environment and the humans themselves add new information. Remote sensing is another source of data: different satellites continuously provide images of the Earth containing information about atmosphere, geology, vegetation and land use dynamics. In addition, such advances as Geographical Information Systems (GISs), which has spread rapidly, are a valuable source of environmental relevant information, for such applications as digital elevation models, insolation assessments and land uses changes.

Most people make use of this information to observe the evolution of certain variables, control abnormal values and write simplified reports. This is an objective in itself. But, without doubt, within such amounts of data there is a lot of hidden information, in terms of models, patterns, trends, etc. Being able to extract this information would give more global perspectives, more interpreted elements, more efficient and reliable environmental and human health indicators, and increase our capability to predict. Such information is difficult to extract, since data is of varying quantity and quality. For one thing, data is abundant and of varying spatial and temporal distribution. In many instances it is too large for a human to process and make useful for the problem at hand. On the other hand, raw data, as collected by people or by sensors, typically include erroneous data.

Missing values, noisy data and non-homogenous data is the usual erroneous data found in files, although in some cases, inconsistent or distorted data for protection reasons may be found (Doyle et al., 2001).

It is, thus, understandable that the field of semi-automatic knowledge extraction from data has gained unusual importance within the economic and scientific community. The fact that all that information is in digital form has also been definitive. Since mathematical modelling and statistics have been useful for decades or even centuries, a question about the novelty in this approach can be raised now. The answer is manifold. But the main reason comes from the fact that those techniques are mainly for validation and it is the user that must provide the model, leaving the task of calibrating and adjusting parameters to statistics. Further, to perform this task the user must have some mathematical and statistical knowledge (Izquierdo et al., 2004a). This is the classical theory-driven paradigm for modelling. Nevertheless, the need for decision making requires new, unexpected and not manually but electronically derived models from such bulky data. This kind of knowledge, in addition, should not require specialised skills. The new paradigm is a data-driven one (Abbot et al., 2001). We are speaking about Knowledge Discovery from Databases (KDD), defined by Fayyad et al. (1996) as "the non-trivial process of identifying valid, novel, potentially useful and, ultimately, understandable patterns in data".

Given the vast broadness of environmental sciences any overview of applications of KDD methods is bound to be incomplete. In this paper we attempt to give an overview of what KDD is and mention some applications in environmental sciences, especially in IWM.

2. The KDD Process

Sometimes KDD is mistaken for Data Mining (DM). But, strictly speaking, DM is devoted to generate and check models and, as such, is only a part of the complex process of KDD (see Figure 1), which is concerned with applying computational techniques (Dzeroski, 2001). Prior to initiation of this process, useful sources of information should be identified, suitable data warehouses designed and navigation and visualization techniques to identify aspects of interest provided. Then the KDD process encompasses three clearly defined stages (Torra, 2003):

1. Pre-processing: devoted to increase the quality of data by means of data cleaning and re-identification procedures.
2. Model building (this is properly DM): using so-called aggregation operators or fusing information by combining several data models.

3. Post-processing (or information extraction): to interpret, transform and represent the extracted patterns, by building summaries and reducing dimensionalities. This phase also includes dissemination and use of the new knowledge.

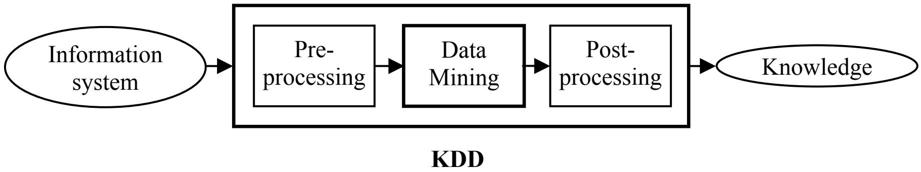

Figure 1. KDD process

We will skip the preprocessing and postprocessing fields, in which considerable efforts are being invested (see Tsumoto (2003); Torra and Domingo-Ferrer (2003); Yager (2003); Keim and Ward (2003), and quotations therein), and consider some of the more popular techniques of DM used in Environmental issues.

3. Data Mining

Once data of interest has been gathered and stored in the warehouse, it is important to decide what kind of pattern one is interested in. The target knowledge governs the DM technique to be used. Fortunately, most DM systems manage to select the technique provided that the user has selected the pattern. Here we present the most common patterns:

- Association of two attributes occurring when the frequency of both being present at the same time is relatively high.
- Dependency shown by one attribute whose value is determined (absolutely or relatively) by another attributes' values. Note that sometimes dependencies are so obvious that they are uninteresting.
- Classification is identifying a set of dependencies that provide a number of rules allowing a dependent parameter to be assigned a value or category among several possible.
- Clustering is the identification of groups of individuals. While in classification the different categories are know a priori, in clustering the groups must be identified. Thus, classification is a supervised process while clustering is unsupervised.

- Trends that allow prediction of the value of a continuous variable that is time dependent, and
- General rules that provide general patterns which do not fit any of the previous ones.

Once the pattern has been determined either the system or the user selects the most suitable technique. Pattern representation can be achieved either by symbolic or non symbolic techniques. Non symbolic techniques are more suitable for continuous variables, but need more clear understanding of the knowledge sought. Among them we have:

- Statistical techniques. A number of statistical techniques can be used to confirm association and dependency. Linear (and non linear) regression and regression networks are perhaps the most important and are used to establish trends.
- Nearest Neighbour methods and their variants together with Instance Based Learning. They are used for classification and clustering by making use of distances and similarity with the prototype or other members of the group.
- Artificial Neural Networks, Fuzzy Logic and Genetic Algorithms and combinations of them. They are very popular (and already traditional) techniques of automatic learning with important applications in classification and clustering. It may be reasonably argued that even though they are able to accurately model many phenomena they do not provide understandability to the model. Nevertheless, some combinations allow rule extraction that is easier to understand.

On the contrary, symbolic techniques provide more readable models and can cope with a broader variety of variables and data structures. Among them we have:

- Decision trees. They are used for classification and clustering purposes through a cascade test that generates a hierarchical structure where each internal node contains a test on an attribute, each branch corresponds to an outcome of the test and each leaf node gives a prediction for the value of the class variable. Regression trees are similar to decision trees but are used for regression analysis instead of classification.
- Inductive Programming and other High Level Symbolic Induction Techniques. They are used to obtain more general patterns. But, the so-called Inductive Logic Programming (ILP) gives some interesting and simpler approximations based on rule induction.

There is a constellation of techniques and combinations of them, and KDD systems keep on incorporating as many as possible. These, together with heuristics advise the user about the better methods for the problem at hand. Given the broad spectrum of both environmental sciences and KDD techniques any overview on the subject is bound to be incomplete. In the following paragraphs only a reduced number of DM model building techniques are introduced, as well as a sample of different applications in the environmental field, mainly related to water aspects, including referenced information about software packages that may be used in implementing the techniques discussed.

4. Environmental KDD. Some Possibilities

4.1. ARTIFICIAL NEURAL NETWORKS (ANN)

The application of ANNs to Environmental Sciences is increasing rapidly. An ANN is a model inspired in the structure of the brain that works well with complicated tasks like pattern recognition, data compression, clustering and optimization. ANNs represent a family of conceptual models, rather than a single technique. Each form of ANN is optimized for a specific set of conditions. A class of ANNs utilizes a training set of labeled data to perform the learning. The labeled data are input patterns together with their right (target) response. This kind of learning is called ***supervised***. But, sometimes, even though a large amount of data is available, there is no clue of how those data are organized, not even for a small subset that could work as training set. In this case only the input patterns are available. Without a target answer to learn, the neural network can only discover by itself typical patterns, regularities, clusters, or any other relationship of interest inside the training set. This is the ***unsupervised*** learning. Among the ANNs belonging to the first paradigm the Multilayer Perceptron (MLP) trained by so-called Back-Propagation (BP) algorithms is the most popular; see, for example, Cichocki and Unbehauen (1993). Among the unsupervised ANNs the Kohonen's Self-Organizing Maps (SOM) are the most popular (Kohonen, 2001). Radial Basis Functions (RBF) learn through a combination of supervised and unsupervised training. For the sake of brevity, we will restrict ourselves here to give a brief description of the Feedforward Neural Networks, a class to which MLPs and RBFs belong.

Feedforward neural networks are able to generalize from previously unseen data when trained by the so-called back-propagation (BP) learning algorithm. This network is a transfer model, in the sense that inputs are limited to provide the outputs in accordance with the learning to which it has been subjected. A MLP consists of a set of input distributed process units (neurons), called first layer or input layer, a set of output neurons, called output layer and one or more intermediate (hidden) layers. The neurons in one layer are interconnected with the neurons of the next layer, by means of connections characterized by certain weights. Neurons receive inputs either from the input data or from the interconnections. The input layer pre-processes the input space, and the other layers, in a forward manner, build up the discrimination surfaces necessary to solve the problem. Finally, the output layer provides the response or output.

In the learning phase the output is compared with the target, which is simultaneously provided with the input data it corresponds to. The errors (discrepancies between output and target) of the output layer are transmitted backwards to the hidden layers progressively. These back-propagating errors are used to adjust the weights of the connections between the layers. The adjustment of the weights between the layers and the calculation of the new outputs constitute an iterative process that is carried out until errors are smaller than a certain tolerance. The learning process is carried out by means of non-linear optimization techniques based on methods such as gradient and conjugate gradient. Some parameters control the learning speed upon influencing the magnitudes in the corrections of the weights after each evaluation of the errors. Thus, showing coupled vectors with input data and the correct response to the network carries out the learning. When comparing target values with those that their current state produces, the network can evaluate the error. This allows readjusting the weights until the error for the vectors decreases to an acceptable value.

ANNs have been used to address several issues in Environmental Sciences. We provide a few examples.

4.1.1. *Environmental Monitoring*

Environmental protection involves 'periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants and animals' (U.S. EPA, 2000). Thus, environmental protection involves monitoring of different variables, which further includes regular sampling, analysis and interpretation of the samples, for example, in terms of water quality. It also involves the study of effects of pollutants on human health. ANNs are used to interpret and classify these samples. Ruck et al. (1993) used ANNs to classify river water quality. Walley and Dzeroski (1996) compared ANNs with other KDD techniques to classify biological samples taken from British rivers. Walley et al. (2000) used unsupervised neural networks to diagnose river quality from biological and environmental data. Rowland et al. (2004), after recognizing that determination of indicators for monitoring the natural environment to ensure ecological sustainability of areas under stress is problematic and prone to bias and that traditionally used statistical techniques present some drawbacks due to quality data, used ANNs to examine ecosystem data in multidimensional space and to select the minimum number of measured indicators that have the greatest weight in maintaining a sustainable ecosystem. In another application, Lingireddy and Brion (2005) considered the use of ANNs to forecast the incidence of cyanobacteria (Anabaena spp.) in the lower reaches of the river Murray of South Australia four weeks in advance of the actual occurrence.

4.1.2. *Forecasting and Time Series Analysis*

ANNs are able not only to solve static problems (output is a direct consequence of certain static input), but also to generate an output pattern or an entire sequence of output patterns from a sequence of input patterns. The goal is to train an appropriate neural network on one side to recognize sequences of input vectors and on the other side to generate the corresponding, possibly sequential, output. This kind of ANN paradigms are called ***dynamic***. To obtain such an evolution process of the network state, backward connections from neurons in one layer to neurons in a previous layer, cross-ward connections among neurons in the same layer and auto-connections of a given neuron with itself are considered into the feed-forward structure. Neural architectures, which present cross and/or auto and/or backward connections, besides the traditional feed-forward connections, are called Recurrent Neural Networks (RNN). RNNs have been shown to be adequate for dynamic learning tasks and, in some cases, to appropriately characterize different dynamic evolutions of the input patterns. In addition to papers devoted to Time Series Analysis in general, like Tronchi et al. (2003), just to quote one, there are several papers considering Time Series Analysis in environmental issues. For example, Anctil and Tape (2004) employed an ANN combined with wavelet decomposition in rainfall-runoff forecasting. River flow forecast for reservoir management through ANNs is considered by Baratti et al. (2003). Panella et al. (2003) used a specific type of neural network to tackle the problem of predicting future values of environmental data sequences. The authors claim that their approach manages to improve the prediction accuracy of real data sequences, which will help the cost effective management of available resources. A time series prediction of pH levels in the eutrophic Middle Loire River, France, using a multilayer perceptron was considered in Lingireddy and Brion (2005). Another time-series application of an ANN, also found in this same reference, was to forecast salinity levels in river Murray, Australia.

4.1.3. *ANNs in Drinking Water and Wastewater Systems*

A plethora of papers also address these issues. Monitoring, control and pilot-scale testing in water distribution systems, for instance, are considered by Izquierdo et al. (2004b), Bhattacharya et al. (2003) and Baxter et al. (2004). Water quality is also considered widely (Millot et al., 2002) and lastly, wastewater aspects can also take advantage of the application of ANNs (El-Din et al., 2004).

4.2. FUZZY LOGIC

In most, if not in all real-world scenarios, we do not have exact measurements. For example, the complexity of the aging process of the pipelines and the difficulty, the cost and the time of performing precise measurements to assess their effective diameter and roughness are values not easily predicted. While the determinist data can be easily included in the models and formulas, the imprecise information represents a problem during modeling. The use of single values (means, for example, or maximum and minimum values), although it implies a quick and sometimes convenient way of calculation, it is often simplistic and it should be corrected with appropriate safety values. On the other hand, to give the problem artificially a statistical character by subjectively attributing probabilities to the inaccuracies, involves a high degree of randomness and runs the clear risk of inventing information of nonexistent distributions. In the context of uncertainty we are interested in the range into which our measurements fall. It is important to underline that this is different from probability, where we deal with the likelihood that a certain crisp measurement is being obtained (Zadeh, 1995). Several approaches to handle information about uncertainty have already been proposed. For example, interval arithmetic allows us to compute with intervals rather than crisp numbers (Moore, 1979). An appropriate conceptual tool for this type of data is the theory of fuzzy sets (Kaufmann and Gupta, 1991; Bardosy and Dukstein, 1995). The concept of fuzzy set was introduced by Lotfi A. Zadeh in 1965, (Zadeh, 1965). It is an approach to deal with imprecise concepts based on fuzzy logic. This type of logic enables us to handle uncertainty in an intuitive and natural manner. It allows formalizing imprecise numbers, but also enables arithmetic operations with *fuzzy* numbers. The classical theory of sets can be extended to handle partial membership, thus making it possible to express vague human concepts using fuzzy sets and also to describe the corresponding inference systems based on fuzzy rules. Another interesting feature of using fuzzy systems is the ability to granulate information, that is to say, to consider information at desired levels of specificity. By using fuzzy clusters of similarity we can hide unwanted or useless information, ultimately leading to systems where the granulation can be used to focus the analysis on aspects of interest to the user (Bargiela and Pedrycz, 2003). Fuzzy systems can be, then, used for the analysis of data sets. Fuzzy set theory can be combined with other Data Mining techniques. For example, in Jacob (2003) the fine-tuning of fuzzy inference rules using genetic algorithms is addressed. Also, fuzzy rules can be used to inject expert knowledge into neural networks, and training algorithms from this area can then be used to adjust the membership functions of the corresponding rules. Nauck et al. (1997) describe such Neuro-Fuzzy Systems in detail.

As an example, Bazartseren et al. (2003) used a neuro-fuzzy approach to perform a comparative study on a short-term water level prediction using ANNs, which proved to handle situations with scarce data, and where the predictions are based on the upstream hydrological conditions only. In Juang (2003) a dynamic fuzzy network based on genetic algorithms with variable length chromosomes is designed to address temporal problems. Also dealing with time series analysis Oh and Pedrycz (2003) make use of polynomial neural networks based on fuzzy polynomial neurons. More specific applications are given in Kuncheva et al. (2000), where a fuzzy model of heavy metal loadings in the Liverpool Bay is constructed, and Faye et al. (2003), who proposed a complete approach for long-term storage/transfer/distribution system management of water resource systems using fuzzy set theory. Edwards et al. (2005) have shown the relevance of using an aggregate vs. an individual based model of water consumption to depend highly on the information available on the resource.

4.3. GENETIC ALGORITHMS

Modern machine learning and data analysis hinge on sophisticated search techniques. Computer systems that are able to extract information from large amounts of data, that is to say, to perform Data Mining tasks, like pattern recognition, classification, diagnosis, etc. and, in general, systems that are adaptive and show capacity to learn, fundamentally rely on effective and efficient search techniques. Any adaptive system needs some kind of search mechanism in order to explore a feature space describing all possible states of the system. Usually, the interest lies on seeking optimal or close to optimal configurations or states for the application at hand. For instance, the parameters that define (calibrate) a particular model, the habitat preferences of certain species, the parameters describing a sustainable and efficiently controlled ecosystem, the weights of a neural network for correct classification of some data, the diameters and layout design for an economically optimum (and reliable) water distribution network, are a few examples. In general, exploration in high-dimensional and multi-modal spaces is needed. High dimensionality makes the design of appropriate search techniques a really complex problem. Multi-dimensionality means that there is no single global optimum, instead many local (sometimes) interesting optima can be found. In general, finding the global optimum of an objective function that has many degrees of freedom and is subjected to conflicting, and frequently subjective, constrains is an NP-complete problem, since the objective function is likely to have many local optima. Most relevant problems are of this kind of hard optimization problems. Procedures to explore their state spaces should sample this multi-modal space in such a way that there is high probability of discovering near-optimal solutions. Besides, the associated technique should show efficient implementation. During the last two decades, some algorithms that imitate certain natural principles have been used in different aspects of environmental science. Among them, the genetic algorithms (GA), a subclass of search methods by means of the artificial evolution based on the natural selection and on mechanisms of population genetics called *evolution programs*, (Michalewicz, 1994), are the most popular. This type of search evolves through successive generations, improving the characteristics of the potential solutions by means of mechanisms inspired by biology.

Calibration of parameters used in a water quality model for the pollution of receiving waters using GAs is demonstrated by López (2001), Espert et al. (1999) and Nishida et al. (2004). Several habitat suitability modelling applications of different DM techniques, especially GA techniques, are described in Fielding (1999). Jeffers (1999) uses genetic algorithms to discover rules that describe habitat preferences for aquatic species in some British rivers. Optimum design of water distribution networks including reliability and using GAs are considered by Wu and Simpson (2002), Matías (2004) and Iglesias et al. (2005). Rehabilitation of sewage networks are addressed by Vojinovic and Solomatine (2005) by using GAs. Current trends are towards combinations of ANNs, Fuzzy Logic and GAs, which are showing great promise in applications to many problems. As an example, in Oh et al. (2003) a general category of multi-fuzzy-neural networks using mechanisms of genetic optimization is introduced and used to model NO_x emissions of a power plant.

4.4. DECISION TREES AND INDUCTION RULES

There are techniques and methods able to derive models from data in a symbolic way. They are hierarchical structures providing information in the form of conditions that are more understandable to human beings than neural networks, sometime called black-boxes, and also to semi-automatic systems that process rules. In this way these techniques are, among the DM modelling techniques, the more understandable and simple to use. A decision tree is a hierarchical structure, where each internal node contains a test of an attribute, each branch corresponds to an outcome of the test, and each leaf node gives a prediction for the value of the class variable. Decision trees have been used for decades and are especially suited to represent procedures in many fields. The main characteristic of a decision tree is that a certain condition leads to mutually exclusive states. To analyze a certain situation one has to follow the tree in a logical manner to eventually reach a single leaf, that is an action or decision to take. On the other hand, induction rules are a generalization of decision trees in which exhaustivity is not mandatory. In this way, it is feasible that more than one rule could be eligible. A rule is a pattern of the form 'IF Conjunction of conditions THEN Conclusion'. The individual conditions in the Conjunction will test the values of individual attributes. The conclusion gives a prediction for the value of the target (class) variable. A set of ordered rules is called a decision list. Rules in the list are considered from the top to the bottom of the list. The first rule that applies to a given example is used to predict its class value. A decision tree can always be transformed into a decision list with each of the leaves of the classification tree corresponding to classification rule in the list. On the contrary, decision lists cannot always be transformed into decision trees. Decision trees are best suited for classification. Since classification deals with disjoint classes a decision tree will lead an example to a unique leaf, thus assigning a unique class to the object. This property is the simple idea behind the first learning algorithms for decision trees. Following a divide-and-conquer strategy they manage to completely classify the space according to a certain partition. The criterion adopted to design such a partition gives rise to the different algorithms to build decision trees. The most important of them are CART (Breiman et al., 1984), ID3 (Quinlan, 1983, 1986), C4.5 (Quinlan, 1993) and Assistant (Cestnik et al., 1987). Induction rules do not follow necessarily the exhaustivity criterion but sometimes manage to classify information in a more suitable way. Thus, instead of using a partition of the space, rules are generated one after the other as more and more examples are covered. Eventually, it is possible, then, to obtain overlapping rules. The so-called covering algorithm is used to generate the rules. This algorithm works as follows. First a rule is built that correctly classifies some examples. Then the rule-positive examples are removed from the training set and the process is repeated until no more examples remain. There are several implementations of the covering algorithm. The most important are AQ (Michalski and Larson, 1983; Michalski et al., 1986), CN2 (Clark and Niblett, 1989; Clark and Boswell, 1991), FOIL (Quinlan, 1990; Quinlan and Cameron-Jones, 1993) and FFOIL (Quinlan, 1996).

Decision trees are used by Solomatine and Dulal (2003), Solomatine and Siek (2004) and Bhattacharya et al. (2005) (amongst others) to model rainfall-runoff, flow prediction and water level discharge processes, respectively. Dzeroski (2002) makes use of decision trees for biological classification of river water quality. In Babovic et al. (2002) water supply assets are classified by using decision trees. Bessler et al. (2003) used them for water reservoir control. Decision trees are also used in Díaz et al. (2005) to obtain socio-economic-demographic data from consumption records of a water distribution system.

5. Software for KDD

DM is under permanent evolution. New techniques are presented, existing techniques are improved, software market changes and new application areas appear every day. Thus, it is difficult both to give an exhaustive overview of the existing tools and to select a suitable tool for a given application. There are several Internet sites where to find specific information and this helps to find the right solution for the data analysis problem at hand. We restrict ourselves to quote two of the most popular ones.

- http://www.kdnuggets.com/ (KD stands for Knowledge Discovery) is an important source of information on Data Mining, Web Mining, Knowledge Discovery, and Decision Support Topics, including News, Software, Solutions, Companies, Jobs, Courses, Meetings, Publications, and more. Of special interest is the link devoted to *software*, a directory of general purpose DM software, and the sub-links *classification* including decision-tree and neural network models and other approaches, and *suites* giving a broad overview of both commercial and free DM and KD software packages. It is also worth mentioning *KDnuggets News*, a bi-weekly publication that has been widely recognized as the leading newsletter on Data Mining and Knowledge Discovery.
- EvoWeb, http://evonet.lri.fr/index.php, website of EvoNet - the European Network of Excellence in Evolutionary Computing - is another interesting Internet site that fosters innovation, training and technology transfer, and provides comprehensive information mainly in the field of evolutionary computing, although other DM aspects are also considered.

6. Conclusions and Future Developments

Many papers have been written during the last 10 or 15 years that use KDD techniques to tackle problems in many areas and, in particular, in environmental fields like integrated management of water resources (IWM). These techniques have been found useful for approximating the traditional or knowledge-driven models but also for identification and learning the relationships and patterns hidden on measured data obtained from processes that are too complex (highly uncertain and non-linear) to be described by the theory-based models.

The advantages of using KDD techniques for water and environmental related problems could be synthesized into the following categories:

- KDD techniques may be used either to replace knowledge-based models or to complement them and produce so-called hybrid models;

- A particular domain area will benefit from data-driven modelling if:

  there is a considerable amount of data available;
  there are no considerable changes to the modelled system during the period covered by modelling;
  it is difficult to build physically-driven simulation models, or they are not sufficiently adequate;
  there is a necessity to validate the results of simulation models with other types of models.
- It is not necessary to have an in-depth knowledge of the process under consideration, but modeller's experience is usually very important, requiring proper preparation: analysis of logical relations between different variables, choice of these variables, proper data collection, pre-processing,…
- KDD models are usually faster than theory-based models relying on numerical solutions of traditional integro-differential models.

The future is seen in using hybrid approaches combining models of different types and following different modelling paradigms, including the combination with physically-based models. It can be foreseen that the computational intelligence (machine learning) will be used not only for building data-driven models, but also for building optimal adaptive model structures of such hybrid models. Also, Granular Computing (GC), concerning the process of complex information entities through information granules, is an emerging conceptual computing paradigm permeating numerous application domains. By using the ideas behind GC one system can be observed and analysed at different scales in time, space and complexity. Granulation serves 'as an efficient vehicle to modularize one problem', 'helps to get better insight into the essence rather than get buried in unnecessary details', 'serves as an abstraction mechanism that reduces the conceptual burden', and 'is human-centric in the sense that the user, designer, developer are in the centre of all these endeavours' (Bargiela and Pedrycz, 2003). It is not difficult to recognize that these factors occur quite ostensibly in the problems involved in IWM. Being able to recognize suitable abstraction levels and having at one's disposal tools to tackle the problem at hand will be of paramount importance to build any DSS (Decision Support System) useful for IWM. As Bargiela and Pedrycz put it, 'granular computing is knowledge-oriented… Undoubtedly, knowledge inclined processing arises as a cornerstone of data mining, rule-based models, intelligent databases, hierarchical and supervisory control, just to name a few representative examples'.

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NETSYMOD - AN INTEGRATED APPROACH FOR WATER RESOURCES MANAGEMENT

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Abstract. This section presents the NetSyMoD approach – where NetSyMoD stands for Network Analysis – Creative System Modelling – Decision Support. It represents the outcome of several years of research at FEEM in the field of natural resources management, environmental evaluation and decision-making, within the Natural Resources Management Research Programme. NetSyMoD is a flexible and comprehensive methodological framework, which uses a suite of ICT (Information and Communication Technology) tools, aimed at facilitating the involvement of stakeholders or experts in policy- or decision-making processes (P/DMP). A generic P/DMP is formalised in NetSyMoD as a sequence of six main phases: (i) Actors analysis; (ii) Problem analysis; (iii) Creative System Modelling; (iv) DSS design; (v) Analysis of Options; and (vi) Action taking and monitoring. Several variants of the NetSyMoD approach have been applied so far in different contexts: integrated water resources management, agri-environmental policy, coastal management, etc. The various applications of NetSyMoD share the same approach for problem analysis and communication within the group of actors, based upon the use of creative thinking techniques, the formalisation of human-environment relationships through the DPSIR framework, and the use of multi-criteria analysis through the DSS software. The

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NetSyMoD framework was devised to tackle problems commonly encountered under integrated water management, as it originated from a series of European research projects in support of the EU Water Framework Directive. Experiences showed that the framework can be applied more broadly to any other field of environmental modelling and decision making, in which an integrated approach is needed, in a public participation context.

Keywords: social network, integrated analysis, participatory modelling, decision support

1. NetSyMoD: Main Aims and Features

NetSyMoD stands for Network Analysis – Creative System Modelling – Decision Support. The NetSyMoD methodology represents the result of several years of research at FEEM in the fields of resource management, environmental evaluation, and decision-making within the Natural Resources Management Research Programme.

NetSyMoD presents a flexible but rigorous and comprehensive methodological framework, which uses a suite of tools aimed at facilitating the involvement of actors (stakeholders and/or experts) in policy- decision-making processes (P/DMPs). In these contexts, decision is intended in a broad sense, to include any process in which a choice has to be made by examining the information available on the given issue. The problem itself, the information, and the choice set are defined with the contribution of different actors, who may be various experts in the disciplines relevant for the solution of a certain problem, or the stakeholders and the decision makers that are either formally or informally involved in the participatory process of decision-making, for instance during the definition of a local development plan.

NetSyMoD is clearly not intended to provide a single methodological approach for each and every possible application context, given the variety of situations in which public participation may be required. The emphasis is on integrating and implementing within the same framework different state-of-the-art approaches and tools for decision support: from the more traditional use of simulation models in the decision process through the development of ad hoc decision support systems, to the more innovative creative thinking approaches for participatory modelling design.

The main common components of NetSyMoD are depicted in Figure 1, which also represents the sequence of phases and possible iterations.

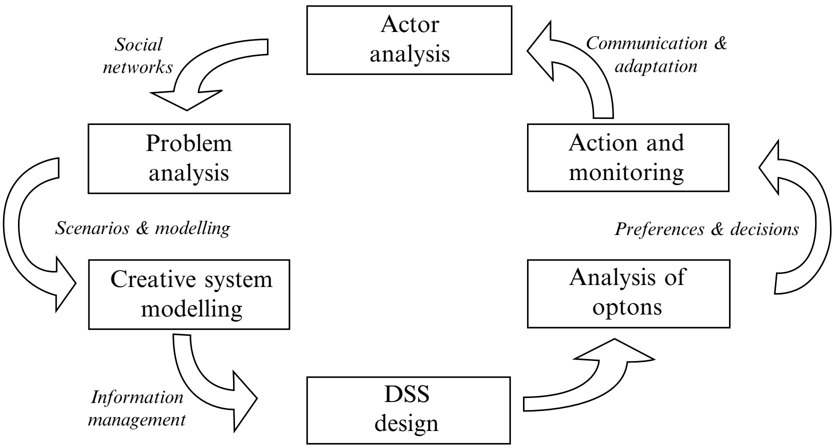

Figure 1. The six main phases of NetSyMoD.

In the first phase, relevant actors (stakeholders, experts), are identified and their reciprocal relationships within social networks are assessed. Once a sort of community of interested parties has been formed, the problem concerning the decision to be taken is explored and formalised. Mental modelling and cognitive mapping techniques provide the analytical tools to develop a conceptual model (i.e. a simplified representation of the part of the reality of interest) shared by the group of interested actors. Such formal description of the human-environmental system and its causal links may in turn provide the framework for implementing complex mathematical models, which hereafter form the interface for easier communication with the interested parties, and provide robust scientific bases for the development of decision support systems. Decision Support System (DSS) tools in turn provide the interface between science and policy/decision making and the methods for selecting the preferred alternative option. The implementation of the courses of action foreseen by the selected option and the monitoring of their effectiveness, may then initiate subsequent iteration and adaptations.

The main rationale behind NetSyMoD is that creative system modelling and participatory techniques can provide not only a common ground for mutual understanding among the parties involved, but also a scientifically sound basis for the development of effective decision support systems. DSS tools may in turn be based upon complex mathematical models, which may find in the methodology proposed an interface for easier uptake and communication with the interested public. As demonstrated by the scientific literature, building a decision support system tool in a participatory way improves the performance of the tool, increases its acceptability – and, ultimately, the acceptability of the decisions taken with its support. The process of participatory model-building itself may bring about substantial benefits and improvements for natural resource management, in terms of increased knowledge and awareness, reduction of conflicts, and easier implementation of the selected management strategies.

The framework was devised primarily to facilitate the integrated water resource management but the problems addressed are similar to those of other environmental issues. The uneven distribution of water resources, amplified by numerous conflicting water uses, constrains economic development and the wellbeing of humans. The excessive quantity of water as a result of land use and/or climate change (and thus at least partly accountable to human activities) poses additional threats. To ensure an efficient allocation and protection of water, a holistic (integrated/comprehensive) management based on the principles of the ecosystem approach was endorsed by a broad scientific and policy community. Such management was aimed at promoting pro-active, non-structural and demand-side interventions favouring a more cautious exploitation of resources. In this context, the NetSyMoD framework acts as a catalyst of integrated and adaptive water governance.

2. Public Participation

2.1. BACKGROUND

Public Participation (PP) is intended as a process to improve decision-making, by ensuring that decisions are soundly based on shared knowledge, experiences and scientific evidence, that decisions are influenced by the views and experience of those affected by them, that innovative and creative options are considered, and that the new arrangements are workable and acceptable to the public. The commonly agreed view is that co-operative approaches that make participation a rewarding experience are achieving better results than more coercive approaches. Participatory and learning-based approaches to decision-making and management are useful for developing a common understanding of environmental problems and are adaptive processes in which technologies and behaviours are continually reviewed and fine-tuned.

For instance, according to the Guidance on PP in relation to the Water Framework Directive (2003), some potential benefits of public participation processes are:

- increasing public awareness of environmental issues;
- making use of knowledge, experience and initiatives of the different stakeholders and thus improving the quality of the decisions;
- public acceptance, commitment and support with regard to decision-taking processes;
- more transparent and more creative decision-making;
- less litigation, misunderstanding, fewer delays and more effective implementation;
- social learning and experience.

At the basis of a meaningful participation process there are several important prerequisites such as: providing the stakeholders with relevant information; building knowledge about the issue at stake; having the suitable resources to start a PP process; designing a clear time table. In the present context, the participation process is to be used for modelling design in order to provide the community of actors with a shared causal model describing the socio-eco-system interested by the decision.

It is of utmost importance to bear in mind that PP is a complex process for which no blueprint exists and therefore it has to be designed according to the needs, the available means and tools. In particular, in the field of natural resources management, the need emerges to develop and apply robust methodologies for linking formal, analytical tools provided by the scientific community and more qualitative information and cognitive models, emerging from stakeholders' participatory approaches. Indeed, although there is wide consensus in viewing PP as both a right and a practical necessity, its forms, mechanisms and functions need to be carefully shaped, to avoid its potential negative consequences (Dalal-Clayton and Bass, 2002). Therefore, it is of utmost importance to carefully design participatory approaches, taking into consideration all the potential negative effects and the shortcomings which can follow, and implementing measures to mitigate them. The first crucial step in a participatory process in practice, including NetSyMoD, is the identification of the actors to be involved.

2.2. ACTORS' IDENTIFICATION

The transparency of the process of actors' identification should be guaranteed by the use of scientific methodologies, assuring the objectivity and impartiality of the choice, and helping in managing relations among actors. The team should be composed of people with a particular interest in the process and its outcomes, and with a suitable mix of expertise for the various components of

NetSyMoD, should implement the methodological framework, and specify the most appropriate methodologies to be used. Such "task force group" (TFG) is usually established by the administration/agency having the competence and the duty to carry out the process and make the final choice. The TFG should include insiders – that are, actors directly involved in the process, familiar with it, or with specific expertise of relevance – and outsiders – people who are not familiar with the issue, but who can provide more objectivity, as well as fresh perspectives, mitigating the potential biases emerging from insiders' pre-existing relationship with experts and stakeholders[1]. The usefulness of involving outsiders in the TFG is limited in the case of experts' consultation, and may thus be omitted without the risk of biasing the process. One or more facilitator(s) are then needed to support the TFG, playing a crucial role for providing the skill for a correct and effective management of participation, in all stages.

There is often confusion over the terms stakeholders, experts, decision makers, etc. The definition provided in the European context by the WFD-CIS (EC, 2003) identifies stakeholders as those who have an interest in a particular decision, either as individuals or representatives of a group. This includes people who influence a decision, or can influence it, as well as those affected by it. On the other hand, experts are researchers, technicians and practitioners who have a specific expertise on the issue at stake, while decision makers are those who carry the formal right and the duty of taking the final decision.

The identification of stakeholders in a specific situation can be performed by means of a Stakeholder Analysis (SA) which, in addition to providing an overview of all the relevant actors in the field of interest, allows:

- identifying the key stakeholders to involve in the participatory process;
- assessing stakeholders' interests and influence and the ways in which those interests affect the decision-making process;
- identifying, in a qualitative way, the relationships between stakeholders.

In the NetSyMoD approach, a simple methodology is proposed for the identification of stakeholders and experts. The main aim is to map all the actors potentially related to the issue at stake in the case of stakeholders' identification, or all the experts in relevant fields in case of experts' identification. This is the preliminary step which, coupled with the Social Network Analysis (SNA), allows to understand the connections between the selected actors, and to identify only

[1] Although some literature suggests the involvement of up to 10 persons, for the sake of efficiency in the management of the meeting within the NetSyMod context it is suggested to keep the size of the TFG below this number, with a minimum of 4 members.

the key stakeholders/experts to be involved in the core of the participatory modelling process.

The approach here proposed is flexible enough to be applied in a variety of contexts and at different scales, and is at the same time rigorous to reduce the risk of omitting important actors in the participation process. The first step is to draft a list of all the stakeholders/experts with a potential interest in the issue under investigation, and to compile their profile. Within the NetSyMoD framework, this first task is carried out in a kick-off meeting (see Figure 2 for a graphical representation of a typical implementation of a NetSyMoD process) by the Task Force Group (TFG). A team approach is likely to be more effective and, above all, more reliable than a single individual doing the identification process. A team can compensate for, and neutralise, individual biases, as well as provide a more objective perspective of stakeholders/experts position and interests.

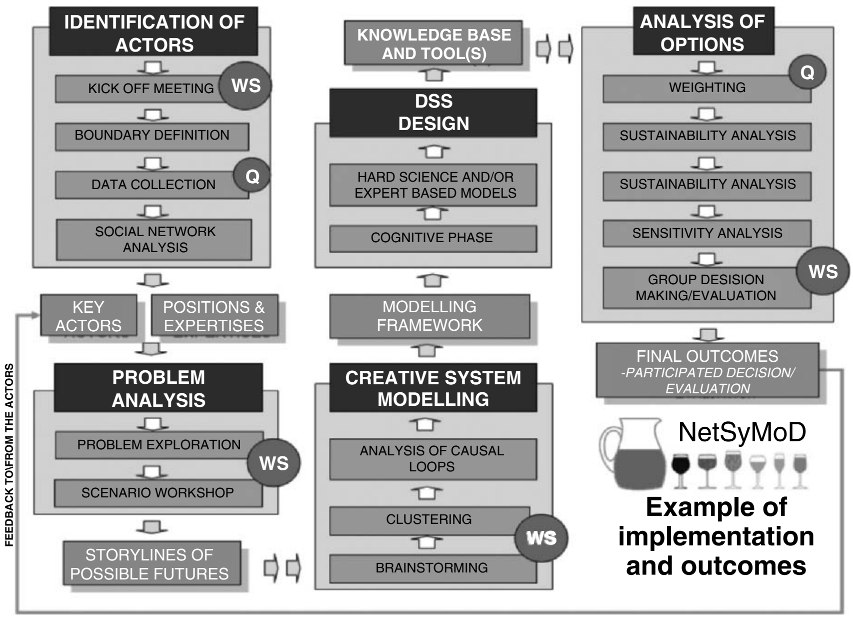

Figure 2. A graphical scheme of the NetSyMoD approach in details.

During the kick-off meeting (named WS in Figure 2, as it should be the first workshop of the NetSyMoD process), the first objective is to specify the decision context, and to draft a list of criteria defining the boundaries of the actors' set, a necessary step prior to the compilation of the actors' list.

These criteria (ad hoc boundaries) differ according to whether the TFG is identifying stakeholders or experts, since the involvement of the two groups drives to different outcomes. In the case of expert identification the *ad hoc* boundaries depend on several factors, such as the scale of the issue under investigation. It is always good practice to include a good mix of experts with a strong scientific background, and also those with sound empirical knowledge.

At this stage members of the team are required to individually identify groups or organisations rather than specify contact persons. Checklist questions can be used, with the help of the facilitator, to ensure that members of the TFG are satisfied with their lists. Once checked, the individual lists can be consolidated and agreed upon by the team. It is in this stage that contact persons should be identified by the group, and with the help of the facilitator.

During the meeting, members of the TFG could also compile preliminary stakeholder/expert profiles, based on a well-specified profiling form. In the case of stakeholders, it is the organisation and position of actors that need to be profiled. The exercise allows TFG members to gain a better understanding of the reference group, as well as helping them ensure that all key aspects and roles of the decision-making process have been considered.

There may be cases in which the boundaries of the population are not clear-cut, or easy to delimit using a set of identified criteria. Under such circumstances, there is a specific sampling methodology which can be of use for the implementation of PP within the NetSyMoD framework. The snowball sampling technique (see, for instance, Varvasosovsky and Brugha, 2000) can be used to complete the list drafted during the brainstorming exercise, making it more sound and reliable and ensuring that all the relevant actors have been included. The basic idea behind this method is that actors are not selected from a sampling frame, but from the linked network of existing members of the sample. This process of sampling continues until the research team is reasonably confident of having identified all main stakeholders.

At this stage a questionnaire (Q), should be used for collecting data and information from the identified actors regarding the problem specification, and to be used for the SNA.

2.3. SOCIAL NETWORK ANALYSIS

Social Network Analysis (SNA) is a framework strategy for investigating social structures, a methodology which enables researchers to translate core concepts of social and behavioural theories into a formal language, based on relational terms. In this way, theories which would otherwise be fuzzy and difficult to analyse can be quantified and explored in a systematic and objective way. Wetherell et al., 1994 provide a useful definition of SNA: “Most broadly, social network analysis (1) conceptualises social structures as a network with ties connecting members and channelling resources, (2) focuses on the characteristics of ties rather than on the characteristics of the individual members, and (3) views communities as 'personal communities', that is, as networks of individual relations that people foster, maintain, and use in the course of their daily lives." (p. 645).

SNA provides procedures to determine how a social system behaves, and mathematical and statistical methods to test the validity of theoretical underlying hypotheses of human behaviour and interactions (Wasserman and Faust, 1994).

Within the NetSyMoD approach, Actors' identification and SNA help organise the problem conceptualisation and building phase and managing stakeholders' interactions during Problem analysis and Creative Thinking and System Modelling phases, ensuring that important actors are not excluded from the process – but also that the process is simplified by excluding those actors whose ideas are similar, and can be promoted by a representative. Characterising the power structure prevalent in the selected group of stakeholders will also ensure that the participatory modelling and/or planning process is not hijacked by powerful groups, but rather, is truly representative of the whole sample – and population – of interested parties.

In SNA, *actors* can be individuals, groups, corporations, and the like. The important feature is that actors are seen as interdependent and not autonomous, but they are social entities. *Relations ties* establish a linkage between pairs of actors (a *dyad*), allowing them to interact in different ways: relations may, for instance, express the evaluation of actors with respect to one another, or they may quantify transfer of resources between actors; there may be behavioural interactions between actors, or physical connections. Ties may either be present or absent, or they may have different strengths/values associated with them, etc. Actors and relations together form networks: networks, therefore, are the results of a process of defining a group of actors on which ties are to be measured.

The first step in SNA is to specify the unit of observation, on the basis of the preliminary definition of the problem. This involves determining both the entity on which measures are taken, together with the level at which information will be summarised and clear specification of the type of relations to be investigated (what is sometimes called in the literature as "name generator"). It is the theory underpinning the empirical analysis which will direct the researcher with respect to the type of relation/tie to be used.

The next step in a SNA is the choice of data collection techniques. There is a variety of techniques available for the collection of social network data (see Table 1), and the final choice will ultimately depend on the contingent situation

TABLE 1. Main data collection approaches.

Questionnaires	Should be used when the respondents can answer the questions directly, or when the respondent is a representative of an entity. In addition, questionnaires can also be used to structure face-to-face or telephone interviews.
Interviews	Telephone or face-to-face interviews are often used to gather data on egocentric networks. With this technique, there is a need to identify the right line of questioning, and minimise interviewer bias by providing a standard checklist that should be followed. Open-ended questions should be preferred.
Diaries	Actors are asked to keep a diary of their interactions (frequency, type, etc.) for a specified length of time. Diaries can provide very reliable information, but they require strong commitment on behalf of the actor.
Direct observations	Can be used in field research when the actors are relatively homogenous, small in number, and have face-to-face interactions. The recorded ties are based on researchers' impressions, though, and may therefore be more subject to biases.
Cognitive social structure	Measure the perceived relations among actors other than the ones directly observed/interviewed. Respondents are asked to give their opinion on ties among other actors. This method could be used when there is a very small sample, thought to be highly representative of the population of actors.
Experimental methods (e.g. role-playing games)	The researchers observe behaviour of actors in an experimental setting. Actors can either be playing their own role to solve a problem similar to the one they face normally, or they can be assigned a role by the researchers. Experimental methods can be useful at the very early stage of research, when the problem has not been clearly identified, and needs to be further explored.

(both in terms of the size of the actors' set, the problem to be addressed, and the time and resources available). Most of the information for SNA is obtained by directly questioning/interviewing actors about the ties they form with other actors in the sub-set, or by directly observing their behaviour.

The final step in SNA consists in analysing the data collected. There are many formal statistical and graphical considerations which can be done on data of social networks, and the selection of the most appropriate level of analysis depends on the purpose of the research. The basic idea of network analysis is to characterise the position occupied by individual actors within the network – where by position we mean the space in the network as defined by the way in which occupants of a certain position relate to actors in other positions (Wasserman and Faust, 1994). The concept of social position refers to a collection of actors embedded in similar ways in the network, whereas the concept of role explores the behaviour expected of a person occupying a particular social position. Social positions and role are characterised often by measures of centrality and prestige – which can be calculated at the individual level or at the group level. Centrality measures allow the identification of important actors in the network, and the power relations amongst actors. Positional analysis has the main aim of simplifying information by representing the network in terms of the positions identified by an equivalence definition and a statement of how these positions are related to each other.

There are three main steps necessary to carry out the SNA within NetSyMoD – data collection, data analysis and validation. These are described in the next sections.

2.3.1. *Data collection*

The preferred data collection methodology within the NetSyMoD framework is the use of questionnaires, possibly with semi-structured interviews. When experts' opinions and views are sought, archive searches will be used to build the network, while a reduced-form questionnaire will be used to gain a first brush of the problem from the experts' point of view.

In general, the questionnaire should be structured with both open-ended and close-ended questions: the former are particularly useful in interviews, as they leave space for the respondent to freely describe his/her experience with respect to the issue. Close-ended questions, on the other hand, are less problematic both analytically, and psychologically, as they minimise biases in responses. A mix of the two is therefore likely to provide more information, with in-built reliability check and balances. Three main sections are envisaged:

1) *Stakeholders' identification:* key attributes of the person interviewed should be recorded in this section, including affiliation and role.

2) *Stakeholders' relations:* this section is the core of the questionnaire, in that the information gathered will allow the researchers to assess actors' structural equivalence, and power relation. The interviewees will be asked to identify the actors whom they interact with and the type of the existing relationships (ask advice from; give advice to; communicate actions, etc.). The *frequency* of relations will also be measured using five-point frequency scales[2], with the time interval depending on the case at hand.

3) *Stakeholders' views of the problem:* which collects information on stakeholders' understanding of the specific decision-making problem, as well as their preferences. The objectives are twofold: on the one hand, to supplement

[2] The most commonly used approach to measure the strength of valued relation is to use binary scales, yet this method does not always give reliable results. According to some empirical studies (e.g. Ferligoj, Anuska and Hlebec, Valentina, 1999. Evaluation of social network measurement instruments, Social Networks 21, pp. 111-130.), five-point scale is the most reliable approach. One can also use the line drawing scale (whose reliability is somewhere in the middle) (length of line indicates strength). Ordinal scale seem to produce the best result for reporting strength.

the positional analysis and identify stakeholders with similar or opposing views; and, on the other hand, to support the organisation and implementation of the Scenario Development workshop (if needed) or the Creative System Modelling workshop. It should include information regarding both the problems, and the preferred management responses. When Multiple Criteria Decision Methods (MCDMs) are to be implemented in the decision phase a section can be dedicated to the development or consolidation of the list of criteria to be adopted for the final choice and the actor's preferences for their weighting.

2.3.2. *Data Analysis*

Data analysis can be grouped in three different categories:

1) *Graph analysis:* the emerging network will be visualised in a graph, where actors (nodes) are represented by points, and relations (ties) by lines – or arcs – connecting the points. Graph analysis can be done using dedicated software[3], in which mathematical algorithms are implemented to characterise basic properties of the graph, such as the network type (directed vs. non directed), data type (binary vs. weighted), number of nodes, number of outsiders (that is, of isolated nodes), and number of edges.

2) *Positional analysis:* identifies which stakeholders or experts to involve later in the Creative System Modelling. Actors are structurally equivalent if they have identical ties to and from all other actors, and on all types of relations – structurally equivalent actors are, therefore, substitutable and, if two or more actors are structurally equivalent, there is no loss in generality in aggregating them. A similarity threshold should be set up to determine the degree of similarity required for actors to be considered substitutable.

3) *Power analysis:* identifies the synergies and interactions emerging in the network and allows to single out those actors who are in a "central" position in the network – that is, those who play a crucial role, and to whose opinion/position the decision maker needs to pay particular attention to. Traditionally, centrality measures of actors have been considered as good proxies for power position, such as degree centrality, closeness centrality, and betweeness centrality (Freeman, 1979). For group decision-making problems, which are the natural applications of the NetSyMoD methodology, the choice of the measure of centrality is critical (Bavelas, 1950 Leavitt, 1951 Freeman et al., 1980). It is suggested that, within the NetSyMoD application, betweens centrality should be preferred as a basic reference for actors' power.

[3] There is a wealth of software available for SNA analysis and visualisation, such as AGNA (*Applied Graph and Network Analysis*), AGD, RE, Egonet, GraphPlot. A list of available software can be found at http://www.insna.org/INSNA/soft_inf.html.

4) *Conflict analysis:* potential and actual – among actors with respect to the issue at stake (value divides analysis), and the identification of possible entry points to modify actors' behaviour (value drivers), may play a very important role in complex decision processes. If conflict areas are not identified at the outset, they may prevent the Creative System Modelling (CSM) exercise to reach its objectives, and the identification of a shared view of the issue. In order to assess possible conflicts, the main data input will come from the third section of the questionnaire. The measure of cohesion is used to support conflict analysis, by analysisng the total connections between actors (ties for undirected networks, both sending and receiving ties for directed networks), weighted by their length (the longer the link, the lower the weight). Actors belonging to highly cohesive groups with respect to the view of the problem will be less likely to develop conflicting views and behaviours, and vice versa.

2.3.3. *Validation*

There are three main outputs from the SNA phase, which will feed back to the TFG for validation before they become an input into the preparatory phase for the CSM workshop.

First of all, a *list of key stakeholders/experts* to be involved in the workshop will be drawn up as a result of the positional analysis of actors. This will both limit the number of participants to a manageable size, and ensure that no important actors are left out of the exercise.

Secondly, the *analysis of power* will highlight potentially problematic actors and relations, whom the facilitator will need to actively manage during the cognitive mapping workshop.

Finally, *conflict analysis* and overall network analysis, coupled with information regarding stakeholders background and affiliations contained in Part I of the questionnaire will support groups' identification.

3. Problem Analysis and Creative System Modelling

3.1. PROBLEM ANALYSIS

In this phase the problem (or conflict) at hand is scrutinised from various perspectives and viewpoints. The environment in which the problem is embedded is explored and the relevant factors identified.

The problems faced by environmental resource planners and managers are complex and their drivers interwoven. It is necessary to identify the most relevant aspects, by focusing on which the major changes (improvements) can be attained.

The exploration of the problem includes analyses of legal and institutional frameworks, as well as regional economy and the state of environment.

Stakeholders (identified in previous phase – Actor analysis) usually hold different perceptions and beliefs about what are the causes of the problem or how it should be tackled. Different techniques have been developed to surface tacit knowledge and deeply held beliefs, including conflict assessment, problem structuring methods, discourse analysis. The individual perspectives are further elaborated in the next step (Creative system modelling) to facilitate collective learning and shared (agreed) boundaries of the problem.

The problem analysis phase typically provides the decision process with:

1. A list of most relevant drivers governing the perception of the problem;
2. A preliminary list of possible solutions to be assessed;
3. A preliminary set of scenarios regarding the future development of the main drivers and cause-effect relations;
4. A extensive list of indicators against which the performance of the possible solutions (alternative options) should be measured.

The problem analysis phase is conducted by the TFG with the needed support of experts in various disciplines and provides a scientifically robust ground of knowledge and information about the problem, to be further processed with the direct involvement of actors selected in the SNA in the following phase dedicated to the Creative System Modelling.

3.2. CREATIVE THINKING AND MODELLING

The third component of the NetSyMoD methodology is the Creative System Modelling (CSM) phase. This is a key component that makes use of the Actors Identification and Social Network Analysis outcomes in order to give inputs to the following phases of DSS design and Analysis of options.

CSM in the NetSyMoD approach is intended to provide the development of a shared vision of the socio-eco-system affected by the decision in question, within the group of people identified in the Actors' Analysis, with two possible main aims, depending on the case at hand:

i) building a shared model of the problem, based on cause-effects chains and using the DPSIR[4] conceptual model; or

ii) developing shared scenarios, depicting the potential evolutions of the system over time, or under different policies.

[4] Driving Force, Pressure, State, Impact and Response Framework, developed and used by the European Environmental Agency (EEA, European Environmental Agency, 1999. Environmental indicators: Typology and Overview, European Environmental Agency, Copehagen, p. 25.) for environmental reporting purposes.

A shared vision of the reality is needed for the correct evaluation of options and this can be done by developing a common mental model using techniques that facilitate the process of participatory modelling and elicitation of knowledge and preferences from actors, thus building a common understanding of the problem. The CSM will also serve the purpose of identifying evaluation criteria, and eliciting individual and group weights, necessary for the evaluation of policy options through multicriteria analysis.

Creative system modelling provides not only a common ground for the mutual understanding among the parties involved, but also a scientifically sound basis for the development of effective decision support systems (DSSs).

The key actors identified in the first phase may be involved in various ways, typically through a participatory workshop, during which creative thinking and cognitive mapping techniques are used. In this field the international literature is rich, but lacking a reference core of works. There are several reasons for this, such as the relative novelty of the topic, its development in rather distinct research fields (psychology, operation research, physics, natural sciences), all producing their own terminology.

Cognitive maps comprise internally represented concepts and relationships among concepts that an individual can then use to interpret new events. Cognitive mapping (CM) in the NetSyMoD process provides a means for facilitating participatory modelling and surfacing actors' beliefs and preferences. At the same time it is useful to gain insight into the problem from other perspectives, and this may then facilitate the process of decision-making, as well as encourage negotiations and help to reduce conflicts.

In practice, the key actors chosen in the previous steps of the NetSyMoD approach are involved in a workshop where the most suitable cognitive mapping technique for the specific case is applied.

Many alternative techniques are available, for example, when dealing with experts for the elicitation of cognitive maps, techniques based on the Hodgson's hexagons approach (Hodgson, 1992) or one of the many versions of the Delphi technique (Dalkey and Helmer, 1963) can be utilised. Another useful approach that can be adopted is that of causal scenarios, intended as a cognitive structure to aid in making causal attributions or judging likelihood (see Read, 1987 as well as Tversky and Kahneman, 1973 and Kahneman and Tversky, 1982). Within the concept of causal scenarios, Hodgson (1992) proposed the scenario-thinking concept, which, during the cognitive mapping process, is useful for gathering a wide variety of perspectives from actors. These deeper structures can be modelled with systems methods to help exploring the dynamics of how different end states might emerge. Visual support techniques such as 'hexagon mapping' are recommended. These are the facilitated visual scenario methods that in practice enable the scenario facilitator to utilise a broad range of skills, including group dynamics, creative thinking, visual thinking, and scenario content appreciation.

While planning the CSM workshop the TFG and in particular the workshop facilitator must establish a clear set of objectives and should anticipate the potential workshop stages, bearing in mind the ultimate objectives of NetSyMoD. A practical agenda to be planned during the workshop envisages the *enrolment phase* in the beginning, in which the facilitator explains the CM approach chosen and its goals and introduces participants to the workshop technique by interactive games. During the *brainstorming*, individuals contribute ideas, either anonymously and simultaneously, or through an open discussion. When enough contributions have been made, the concepts are roughly *clustered* by the facilitator and shown back to the group. Further concepts are added as participants review one another's contributions and piggyback one another's ideas in a plenary session. Concepts might be clustered and emerging clusters are validated with the group to establish a goal hierarchy and are then further developed. Linking concepts and *building causal loops* for further evaluation are exploited to initiate discussion around causes and effects and to begin defining a shared meaning of the problem – this is a very important part of the process. Beam projectors or boards with adhesive tags may contribute significantly to the effectiveness of the workshop, allowing participants to monitor the development of the shared vision(s) of the problem. Concepts might be colour coded according to their type (problem, opportunity, strategic aim, etc.), helping with visualising or navigating the cognitive maps and aiding memory and thinking processes. In this way the group identifies a set of key concepts and allow key *indicators* to be preliminarily identified.

Relationships among concepts/indicators can be indicated by *influence diagrams* with arrows connecting those clustered ideas that are causally related and a sign attached to the arrow states if the influence is positive or negative. Then feedback loops can be created. The facilitator guides the formalisation of the cognitive map and its causal links according to the DPSIR framework as a precursor to the development of simulation models embedded in the DSS tool, as described in the following section. These models, when available, may allow for dynamic simulations of the socio-eco-system according to alternative scenarios and, most importantly, following the possible implementation of the various alternative options identified in the Problem analysis phase.

4. DSS Design and Analysis of Options

In the DSS design phase the knowledge developed so far is used for designing the toolbox of procedures and software tools capable of managing the data required for providing informed and robust decision in the following phase of

Analysis of options. This is necessary to manage and to communicate the information flow between various process phases, including exchange, transformation, integration, validation and documentation of gathered knowledge.

Many of the previous analyses employ computer-based tools such as databases (and data management systems), visualisation components, and simulation models. Different tools are frequently assembled into a comprehensive Decision Support Systems, normally employing various interconnected and adapted components, controlled by an user interface. This phase addresses all activities related to the development of useable software components and collection of well documented and easily exchangeable data sets (including spatial data and time series).

While it is beyond the scope of this paper to go into the details of the DSS technology, the Analysis of options and, in particular the role played by Multi-Criteria Analysis (MCA) methods deserve attention.

MCA is both a framework for a decision analysis, consisting of steps and procedures for a piecewise conceptualisation of problems involving multiple objectives and criteria, and a set of techniques aiming at elicitation, introspection and aggregation of decision preferences. Consequently, MCA represents added value to both (i) the decision process (by helping the decision-maker (DM) learn about the decision problem and explore the alternatives available) and (ii) the decision outcome (by helping to elicit value judgements about trade-offs between conflicting objectives).

MCA represents a formal and prescriptive[5] way to decision analysis and is in many aspects similar to other decision tools such as cost benefit analysis (CBA), operational research techniques (OR), or Bayesian networks (BN) (Bromley et al., 2005; Kangas et al., 2000; Katz, 2002; Hauger et al., 2002; Pearce and Howarth, 2000). Common feature of all these techniques is the aid in situations in which pure cognitive decision-making tends to be selective, preferring information which confirms rather than contradicts the belief (susceptible to different biases) and disregarding all but one or two of the most important aspects, anchored to idealised solutions and susceptible to framing effects, prior anchors etc. (Buchanan and Corner, 1997; Hobbs and Meier, 1994; Nape et al., 2003). Formal decision analysis surfaces and questions tacit beliefs and makes value judgements and attitudes explicit. But unlike the other techniques, MCA allows for a variety of the decision criteria, and inconsistent or incomplete judgements/preferences to be implicitly considered in the analysis. Contrary to CBA with which some of MCA techniques (especially value/utility

[5] As opposite to descriptive and normative decision analysis.

function approaches) resemble, the MCA does not attempt to transfer all policy effects into monetary units. The common unit to which all effects are brought is a degree of (subjective perceived) satisfaction of pursed objectives.

Preference analysed by MCA can be imagined as a choice or ranking of alternatives and criteria. They are socially constructed, and they depend on the description and framing of what is being valued, or how the questions are formulated. MCA techniques are suitable to uncover preferences held by individuals and aggregate them across different objectives (intra-personal aggregation) and across different actors (inter-personal aggregation). The full potential of MCA comes in through its combination with deliberative techniques based on active involvement of all actors. The term deliberation here refers to the style and procedure of decision-making, characterised by mutual exchange of arguments and reflections among all participants invited to deliberate (Renn, in press) and a balance-seeking process between conflicting arguments and claims. To this end, MCA is applied in the context of NetSyMoD framework in combination with group modelling and creative thinking techniques.

The wide variety of MCA techniques raises a problem of choosing from many methods. Which method is more appropriate depends on the set of assumptions that seems most valid for a given situation and person. According to Hobbs and Horn (Hobbs and Horn 1997b), the disagreements or inconsistencies between different methods are inevitable and should be welcomed as an expression of the different suitability of a method for a particular situation and a decision-maker. Accordingly, the ultimate aim of MCA is not only to help find a solution to a multicriteria problem, but also to give the decision-maker an opportunity to learn about his/her own preferences. In other words, the process of finding a solution is at least as important as the outcome of the process.

In the NetSyMoD approach, the MCA analysis makes use of the results yielded from the previous steps: only a representative set of stakeholders is invited to take part in a workshop aiming at evaluation of policy options under consideration. During the group modelling workshops, they learned about the expectations and motivations of other participants. This may significantly improve, although never guarantee, the chance of finding a compromise solution everybody is satisfied with. In other words, attainment of unanimity is favoured but not warranted by the deliberative MCA techniques. In addition, at the time of the evaluation workshop, the problem has already been explored in terms of the cause-effect relations; alternatives and scenarios identified and decision criteria agreed upon. The specific task of MCA in this context is to weigh policy outcomes against the objectives, balance trade-offs between conflicting criteria, aggregate preference judgements to a policy ranking and analyse sensitivity of the recommended solution. In the case of persistent conflicts even after the deliberative problem conceptualisation, the analysis has to include also conflict mitigation/resolution using inter-personal preference aggregation.

The decision analysis is normally carried out during a workshop facilitated by a decision analysts or consultant. The success of the workshop depends very much on the ability of the facilitator/moderator to keep neutral position, balance participants' involvement and facilitate consensus (trust) building process.

Similar to the previous stages in the framework, the evaluation workshop may use different ICT tool. In NetSyMoD framework using *m*DSS is recommended. The *m*DSS[6] tool – a generic DSS based on multicriteria evaluation – triggers the evaluation of identified policies and facilitates the MCA analysis (Giupponi et al., 2004; Rittel and Webber, 1973). Originally built on the Simon's design of decision process, involving "conceptual or intelligence", "design" and "choice" phases (Giupponi et al., 2004; Simon, 1960), it further develops to endorse the more iterative and loop-like (spiral) flow of decision process which characterises the NetSyMoD approach. In the current version (*m*DSS 4) the software is integrated into the NetSyMoD framework, making use of the analyses (stakeholder analysis, social network analysis and group modelling) accomplished beforehand. From the previous version the close link to the DPSIR framework is maintained. The DPSIR framework allows for a seamless integration of the results yielded during the group modelling workshop, during which the various aspects of the problem at hand are first identified and then connected to (cause-effect) relations (Figure 3). These relations can finally be brought together to context-dependent cause-effect chains representing the viewpoints of various involved actors. Through aggregation of all actors' viewpoints, a holistic (yet specific to given situation) and multi-dimensional view of causal relationships in human-environmental systems can be obtained. Successively, this is translated into the DPSIR framework.

The DPSIR facilitates the choice of a definite set of alternative policy options from all interventions discussed and pre-assessed during the CSM workshop. This set is considered in the subsequent decision analysis. The *m*DSS software does not provide modelling routines (such as those for the simulation of the hydrologic cycle as affected by the alternative options) but facilitates loose coupling and post-processing of model outputs.

An analysis matrix (AM) is built after the implementation of the DPSIR model, by processing indicator values to convert spatio-temporal data in synthetic values to be stored in the matrix cells, having with options in the

[6] The computer tool (mDSS) is a generic shell providing multiple criteria analysis capabilities for facilitating the use of modelling and the participation of actors in a given decision process. The tool was developed in context of the EU project MULINO (contract No. EVK1-2000-22089).

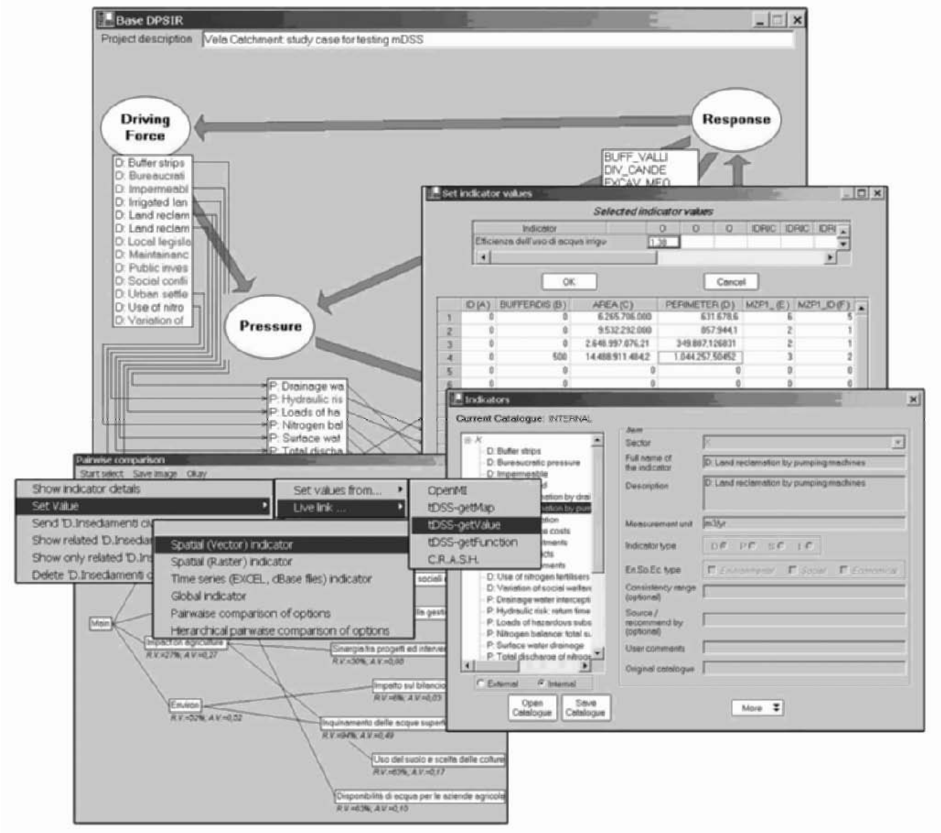

Figure 3. Modelling the conceptual relationship according to the DPSIR framework. Results of cognitive mapping methods and deliberative techniques are translated into DPSIR framework which facilitates the pre-selection of policy options and helps to make decision analysis transparent. Indicators chosen from the DPSIR chains fill the decision matrix which is further elaborated by decision techniques. Several ways are available to fill in the decision matrix, including import (and pre-processing) from spatial databases, time series and model output files. Examples are taken from projects analysing alternative strategies for diffuse pollution control in Italy.

columns and decisional criteria in the rows. The AM thus stores the preferences – performances of the alternative policy options evaluated individually against each decision criterion. At this stage the raw performance measured with different units and/or scales across the criteria is determined.

The decision rules chosen for implementation in the mDSS software are (i) Simple Additive Weighting (SAW); (ii) Order Weighting Average (OWA) (Jiang and Eastman, 2000); (iii) the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and K., 1981); and (v) ELECTRE (Bella et al., 1996; Figueira et al., 2005; Mahmoud and Garcia, 2000; Salminen et al., 1998;

van Huylenbroeck, 1995). In addition, several techniques for elicitation of weights are included such as pairwise comparison, direct rating and hierarchical weighting. The description of these techniques goes beyond the scope of this paper and is well described somewhere else (see for instance Belton and Stewart, 2002). Basically, all decision rules aggregate partial preferences describing individual criteria into a global preference and rank the alternatives.

The robustness of the obtained ranking can be analysed graphically and analytically (Figure 4). Sensitivity analysis (SA) allows examining how robust the final choice is to changes of uncertainty in indicators' values. The main concern of the sensitivity analysis is oriented to the uncertainty addressing the criterion weights. The *m*DSS tool utilises two approaches for SA: (i) the Most Critical Criterion approach (Triantaphyllou, 2000), allowing the identification of the criterion for which the smallest change of current weight may alter the

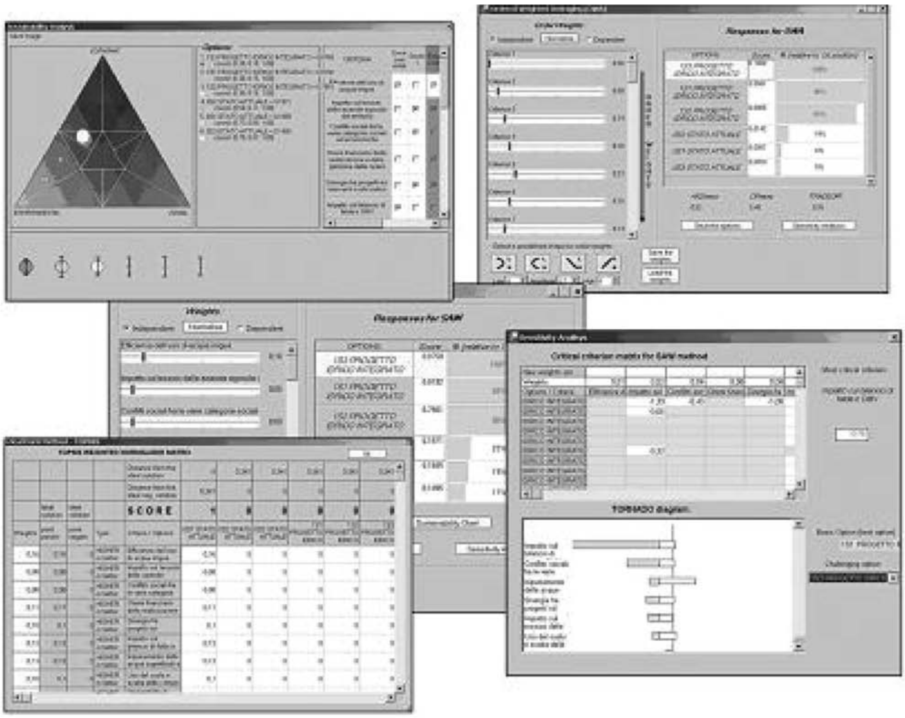

Figure 4. Evaluation of options' performance using multiple criteria decision analysis. Decision matrix is analysed using different decision techniques, each exploring a specific set of problem features and eliciting individual preferences. Options' ranks yielded by different decisions rules can be further elaborated by sensitivity analysis tools and the module for sustainability analysis. If used in a participatory setting, in-built group decision techniques can facilitate the search for compromise building and conflict mitigation. Examples are taken from a study case of integrated water resources planning in an irrigation district in Italy.

current options ranking; and (ii) the Tornado Diagram that compares graphically each option and shows ranges within which the parameters vary and affect the ranking order. The *m*DSS software is equipped also with simple tools to face situations in which several decision makers or different stakeholders are involved in a group decision making context. Routines are thus provided to compare the differences between the weights expressed by different decision makers/interest groups. Three options are available: (1) when the differences are small, and the ranking of options does not change, the software proposes compromise weights lying between the indicated sets; (2) when the rankings are different the users can apply a variety of different techniques including weighted average (Marchant, 1998), and its modifications, Condorcet winner (Gehrlein, 1998, Tataru and Merlin, 1997) to combine them into a single compromise ranking; (3) when the users want to investigate the main discrepancies in assigning the weights among different interest groups, a graphical representation for comparing the weight vectors of different users is provided, to identify the main issues for identifying possible compromise solutions.

5. Summary and Conclusions

In the previous sections, the NetSyMoD framework was presented in terms of tasks and methodological tool-boxes. A fundamental challenge is the quality assessment of policy advices, engendered by the application of such a framework. This regards both the integration of partial results into a final policy recommendation, as well as an assessment of the policy success in terms of on-ground implementation. Neither is a simple task since IWRM in essence refers to conflict management, and quality assessment in this context has to take into account intangible and incommensurable aspects such as subtle changes in behaviour, level of trust, and changes in relations.

The implementation issue is not independent of the lack of unambiguous success metrics. Achievements can be materialised in the decision outcomes (more effective and efficient decisions) and in the (changes to) decision process (more informed, inclusive and transparent decision making). Therefore, quality assessment of an application of the presented framework should take into account both the outcomes and process itself. Besides, the quality assessment has to include a critical reflection about the evaluation itself.

Within DSS/policy advice, judgements of success or failure have to take into account a variety of benefits which go beyond simple measuring whether the policy recommendations were upheld by the policy-makers or not. However, if wider benefits are to be accounted for, the foundation of DSS has to be revised. The definition of DSS must not be restricted to a piece of software but should include a set of supporting methodologies/ techniques, not coded in form of computational algorithms, which facilitate software development, implementtation in a given institutional context and application to a specific management problem.

Over the past years the Natural Resources Management Research programme at FEEM was involved in various attempts to develop DSS tools to advise water policy within the Water Framework Directive (WFD). The NetSyMoD framework presented in these pages is the main methodological outcome of those efforts, applied in different case studies. A comprehensive report about the results from the case studies goes beyond this paper, but remarks could be reported here.

In general, competent administrations in water management are facing the challenge of the choice of methods/techniques out of a number of existing ones. The choice should facilitate exploring different perspectives and choosing a robust policy. Yet, there seems to be a trade-off between these two aspects: the application of multiple methods to learn more about the problems at hand is encountered by policy-makers with scepticism and confusion. Learning that different scientific techniques may end up with divergent recommendations tends in some cases to increase rather than reduce the indecision and hesitation to make a decision.

Moreover, the increasing dependence on a professional moderation of the decision process, adds more problems to the transfer of the developed methods and tools to the policy-makers. The professional moderation is also hampered by a substantial lack of consultants trained in interdisciplinary problem analysis and multi-method policy support.

In conclusion, it seems that progresses have been made over the past years in terms of targeting the needs of policy/decision makers. Methods and tools are now available and are adopted in planning processes, in particular when the involved of trained and motivated experts is facilitated by circumstances such as the inclusion of the study case in a research or demonstration project. More efforts are needed in the future to strengthen the exchanges between research and policy spheres, with particular emphasis in capacity building and training not only of the personnel of competent administrations, but also of those actors, such as private consultants, who may play a very important role as intermediaries for knowledge and technology transfer.

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WATER CONFLICTS: AN UNAVOIDABLE CHALLENGE FROM THE TRANSBOUNDARY TO THE LOCAL DIMENSION

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Abstract. Key features of water conflicts within the context of Integrated Water Resources Management are first identified. The issue of transboundary water resources is briefly discussed and an overview of the main undergoing actions in this sector at the international level is provided. Attention is then moved towards the local dimension with particular reference to the situation of Italy: key water conflicts are depicted, focusing on application of minimum instream flow regulations, flooding and landslide risk, artificialization of water courses, regional water transfer, and multipurpose water management. Finally, some principles and possible solutions are discussed.

Keywords: integrated water resources management (IWRM); transboundary river management; water conflicts; river restoration

1. Introduction

Mankind needs fresh water to live. Water and water bodies are indeed essential for a large number of fundamental human activities, such as drinking and cooking, agriculture, energy production, trade and transportation, and many more. Before that, water is essential for ecosystems, which sustain human life and which in any case deserve the right to exist.

Water, however, is “scarce” in relation to the demand for it, owing to its spatial and temporal distribution as well as to its quality and/or energetic status (Ehrlich et al., 2000). Climate change seems to make spatial and temporal distribution more and more uneven.

P. Meire et al. (eds.), Integrated Water Management: Practical Experiences and Case Studies, 95–112.

The normative/administrative apparatus to manage water is often inadequate, just because it is too complex and/or somehow obsolete; international issues are far from being satisfactorily regulated.

Finally, the knowledge of water bodies (hydrology, groundwater flows and storage, water quality, ecosystem dynamics…) is still definitely incomplete and costly to achieve.

Non-substitutability, high and increasing demand, degrading quality, increaseing scarcity, weak regulatory apparatus, incomplete knowledge are basic ingredients of conflicts between uses and users. Conflict may arise at all scales: global, national, regional, or even local, and may range from clashes among single stakeholders, to real armed conflicts among social groups or nations. Many longstanding water related disputes still remain unresolved.

That is, the integrated management of water resources (IWRM) implies conflicts management, a major challenge of the immediate and long-term future (Wolf et al., 2003).

2. Conflicting Objectives Feed Water Conflicts

The demand for water arises to satisfy several conflicting objectives and interests of different stakeholders. A short insight into the very nature of conflicting objectives and interests is provided here.

Diverging objectives

We want to exploit water for economic-productive purposes, say hydropower generation, or water abstraction for irrigation; but we want lively and natural aquatic ecosystems to be maintained and restored. We want to achieve good quality in all our water bodies; but we want this at minimum cost. We want to maintain sufficient water flow in a river to allow navigation, but at the same time divert water to irrigate agricultural land. We want good water quality to allow fishing and bathing; but we want to use the same water body to discharge wastewaters in it. These are just examples of how pervasive is the presence of conflicting objectives, an unavoidable feature accompanying the management of any scarce natural resource.

Conflicting interests

Behind an objective there always is an interest. It may be the economic interest of a private enterprise, the development mission of a governmental agency, the political ambition of a State, or the ethical motivation of an environmentalist association. In any case, somebody is claiming for something either because he/she wants to gain some direct benefit, or because he/she thinks there is something or somebody else (e.g.: future generations) that have the right to the same benefit (or simply to exist). The interest groups typically undertake an explicit or implicit bargaining process in which each one tries to pull as much as he/she can towards his/her interest. This process is often seen as a "zero-sum game", i.e. a situation where satisfying to a greater extent to one interest (group) implies losing an equivalent amount of satisfaction for another interest (group). This is the essence of the conflict.

A more far-looking vision, however, may often recognize the potential mutual benefits arising from the cooperation of different stakeholders.

Social conflicts

Explicit armed, inter-state conflicts over water may be unlikely; however, water often has a role at the root of armed conflicts labelled as "political", "racial", or "ethnic": controlling water may allow the virtual control of a whole country or population. Nevertheless, water-related conflicts do not necessarily have to take on the attributes of war in order to be debilitating – they may fester between ethnic groups, ignite between neighbouring farmers, or cause the loss of trust between people and their governments, particularly in regions subject to water stress. When water conflict erupts, the victims may not perish on any clearly discernible battlefield, but the people and the water bodies themselves will suffer the consequences of the absence of either cooperation or communication between those sharing a basin. The need to maintain or achieve fair and sustainable access for all people is a key element in many of the world's most tense and conflict prone regions, from Afghanistan to the Balkans, the Middle East and Central Asia. Water was the last and most contentious issue resolved in negotiations over a 1994 peace treaty between Israel and Jordan, and was relegated to "final status" negotiations – along with other most difficult issues such as Jerusalem and refugees – between Israel and the Palestinians. Without access to water, national security and socio-economic stability are all imperilled. This is magnified where water is shared across borders and becomes crucial where water stress exists in regions of religious, territorial or ethnic tension[1].

3. Transboundary Issues and International Regulatory Tools

An important issue is that of international water resources, and particularly *transboundary rivers and aquifers.*

In the absence of proper international institutions and legal tools, actions within a basin can lead to serious conflicts. One of the countries within an international basin may implement on its own a project that impacts at least one of its

[1] Interesting information about "water conflict chronology" can be found in http://worldwater.org/conflictIntro.htm.

neighbours. This is particularly sensitive for downstream countries almost entirely dependent on neighbouring upstream countries as their source of water – such as the Netherlands, Romania, Egypt, Iraq and Botswana. Actions of Ethiopia and Sudan on the Nile river, for instance, may harshly impact downstream Egypt; similar is the case of Turkey's GAP project on the Euphrates.

When such projects proceed without regional consent and cooperation, i.e. without taking into account explicitly possible negative effects on neighbouring regions, they can become an ignition point, stressing tensions and regional instability, and requiring years or, more commonly, decades to clear up.

Especially in the last two decades the international community has expanded its involvement in the management of international freshwater resources. Actions taken have included the adoption of non-binding declarations, the creation of global water institutions, and the codification of international water principles.

The Declaration of the Earth summit in Rio in 1992, and accompanying Agenda 21 action plan, for example, called upon the international community to recognise the multi-sector nature of water resources and to holistically manage the resource within and across national boundaries. Since then, several policy and legal actions have been executed at all scales. These include the passage of new national and international[2] water laws which have introduced or reinforced integrated water resource management concepts; the creation of national and international river basin organisations; and the adoption of international or regional conventions, treaties, and declarations concerning the management of freshwater resources. In addition, the concept of "virtual water," which recognises the "sharing" of water resources between water rich and water poor countries, via trade in agricultural products and manufactured goods, has gained increasing attention in the post-Rio period.

Some data on transboundary river basins

A total of 145 nations include territory within international basins. Twenty-one nations lie entirely within international basins, and, including these, a total of 33 countries have more than 95% of their territory within one or more international basins. These nations are not limited to small countries, but also include, for example Cambodia, Hungary, Bangladesh, Belarus, and Zambia.

Beyond their importance in terms of surface and political area consumed, a look at the number of countries that share individual watercourses highlights the precarious setting of many international basins. Approximately one third of the 263 international basins are shared by more than two countries, and 19 involve

[2] e.g.: the European Water Framework Directive (Dir 60/2000/CE).

five or more sovereign states. Of these nineteen, one basin – the Danube, has 17 riparian nations. 5 basins – the Congo, Niger, Nile, Rhine and Zambezi – are shared by between 9 and 11 countries.

The remaining 13 basins – the Amazon, Ganges-Brahmaputra-Meghna, Lake Chad, Tarim, Aral Sea, Jordan, Kura-Araks, Mekong, Tigris-Euphrates, La Plata, Neman, and Vistula (Wista) – have between 5 and 8 riparian countries.

However, despite these efforts, no international intergovernmental agency exists to facilitate management of transboundary resources, while such an international body or network dedicated to guiding cooperation over water might play a key role.

Evidence shows, on the contrary, that international law and development support for water cooperation over river basins are both currently insufficient. There are also serious institutional weaknesses and the vast majority of states have failed to reconfirm their commitment to cooperate over shared water by neither including this goal in the WSSD agreements, nor ratifying the UN Convention on the Non-Navigational Uses of International Watercourses.

The UN Convention on the Law of the Non-Navigational Uses of International Watercourses (1997).

Adopted in 1997 by the UN General Assembly following 27 years of discussion and negotiations, this is the main post-Rio accomplishment that specifically focuses on transboundary water resources by codifying many of the principles deemed essential by the international community for the management of shared water resources, such as equitable and reasonable utilisation of waters with specific attention to vital human needs; protection of the aquatic environment; and the promotion of co-operative management mechanisms. The document also incorporates provisions concerning data and information exchange and mechanisms for conflict resolution. If ratified, the UN Convention would provide a legally binding framework, at least upon its signatories, for managing international watercourses. Even without ratification, its guidelines are being increasingly invoked in international forums.

So far, though, the Convention has only been signed by 16 countries and ratified by nine mainly downstream countries as Jordan, or Iraq, well below the requisite 35 instruments of ratification needed to bring the Convention into force.

Greater political will and actions are needed, as manifested in earlier declarations, such as those signed in: Rio Declaration (Rio, 1992); the Hague Ministerial Declaration (Hague, 2000); The Bonn Declaration, Third International Forum of Indigenous Peoples and Local Communities on Climate Change (July 14-15, 2001).

It is spontaneous to wonder whether international water disputes may be solved or not. Fortunately, the historical record provides some positive answers. The Senegal River in West Africa provides an example of a functioning institution created in 1972 to deal with issues surrounding competition for water, it survived, after a period of adjustment, a major water-related conflict in the late 1980s in which many thousands of people were killed or had to flee their homes (Turton, 2004). Some of the most unyielding enemies around the world have negotiated water agreements or are in the process of doing so, and the institutions they have created frequently prove to be resilient over time and during periods of otherwise strained relations. The Mekong Committee, for example, has functioned since 1957, exchanging data throughout the Vietnam War. The Indus River Commission survived through two wars between India and Pakistan. And all ten Nile riparian states are currently involved in negotiations over co-operative development of the basin.

These examples of course do not guarantee that no major conflict will be provoked by water disputes between riparian countries challenging for the same vital and scarce resource. Nevertheless, the increasing knowledge of previous conflicts provides ideas and tools for prevention measures and strategies.

River-boundaries

An interesting situation is that of rivers whose water course marks the political-administrative boundary between two (or more) countries. This is the case, for instance, of the river Sava between Croatia and Bosnia-Erzegovina. The peculiar feature of this situation is that rivers move as time elapses; therefore, the boundary and the river certainly, soon or later, will no longer coincide. How can this situation be managed? One solution is trying to fix the river so that "nature is tamed" and forced to follow human needs. This solution, though (as explained in the following) is far from being optimal, or even feasible in general. Another possibility, on the contrary, is recognizing that a river is not only its current water course, but at the same time includes the whole (narrow or very wide) strip of territory where it may need to move in the future. This water corridor, known as "espace de liberté", may tell us much more than just a physical concept. It suggests to manage the boundaries in a very different fashion: no longer sharp, rigid separation; rather, a commonly shared buffer zone where the territory belongs to nature, the river freely evolves, and men can walk in freely before reaching the other country. The result would be more nature conservation, less costly works of river maintenance, less political tension on the boundary, an attractive place to foster the free meeting of people.

4. From Global to Local: The Italian Case

Conflicts do not concern only global or international dimensions: conflicts at the national and local scales, particularly from the perspective of local communities occur in countless cases, covering most of a nation's territory, and therefore they are of great importance. Modifying concessions for water withdrawal from a river including minimum vital flow requirements, managing a multipurpose/multi-actor water reservoir or building a new one, or giving space back to rivers to reduce downstream flooding damages are simple examples of extremely frequent actions and activities often involving harsh conflicts. Italy faces a number of water problems, and several, if not all of them, have the potential to give a rise to water conflicts, involving diverging objectives or interests, at the national, regional and especially local level.

In the following a few examples are outlined.

<u>Minimum Vital Flow (MVF)</u>

Recent European Water Framework Directive (Dir. 60/2000/CE), as well as also previous Italian national laws[3], introduce the obligation to maintain a minimum instream flow in rivers and canals to allow the survival of healthy aquatic ecosystems.

The current situation of water abstraction rights, together with abstraction practice (not always completely coherent with the former), is very often definitely far from fulfilling such a requirement. Huge economic interests are at stake; in particular: hydroelectric power generation with its multiple water schemes often almost drying up entire river stretches in the Alpine region; agricultural production, made possible by large irrigation systems exploiting high fractions of the flow of rivers. Other stakeholders are worth being considered, even though from the solely economic point of view (apart from ethical or environmental reasons): sport fishermen, for instance, with their myriad of small local organizations spread across the whole territory make all together a considerable activity that demands water; rafting, kayaking and other white water sports need sufficient flows to be practiced and sometimes form important parts of local economy.

National river basin authorities and regional administrations are going to face harsh difficulties in the very close future: on one hand, they have to comply with clear legal requirements, most of whose motivations certainly deeply share, and are strongly claimed by a number of "environmental" voices; but on the other hand, they have to consider the strong economic interests stoutly bound to a consolidated status-quo. In addition, the more and more recurrent summer water crises, and the picture of a very warm situation will quickly be apparent.

<u>Flooding and landslide risk</u>

Italy is particularly prone to this kind of risk owing to its geomorphology, soil type, climate and to its high population density.

[3] See in particular L 183/89 and DLgs 152/99.

An intense and extremely costly policy aimed at controlling rivers behaviour has been undertaken since long time ago. Rivers are today straighter, where they were meandering; they are shorter (covering the same drop in a shorter distance); they are narrower because of extensive levee systems; they are deeper (with cases of incision up to 12 meters) because of man-induced activities that blocked sediment transport; they are smoother because of artificial lining; they are more rigid, as they are constrained by several fixed points, like bridges and weirs, abstraction works disseminated by defence works, like gabions, concrete or stone walls. In other words, rivers have been highly “artificialized” (Fig. 1).

Figure 1. The Calopinace river (Calabria, Italy). An example of full artificialization (photo A. Goltara).

The “amazing” thing, though, is that in spite of all these tremendous efforts to canalize rivers and their associated costs, on average the amount of damages is indeed increasing, not declining as desired. And so is the amount of money spent to recover from damages and to control rivers, in an uncontrollable upward spiral (Fig. 2).

The cause may be found, partly, in the climate change issue. Nevertheless the real and profound cause has to be imputed to a literally unsustainable model of land-use, including the very management of rivers just discussed. Urbanization, in particular, has seen in river-flood-plains as the natural possibility for expansion, reclaiming year after year new areas, and progressively narrowing the river beds. Abstraction of sand and gravel from the river beds as construction material, together with the construction of many dams in the 50’s and 60’s, induced severe river bed degradation, again narrowing the river sections. Agriculture has been developed to exploit every corner of usable land. As a result, before, the river could expand and flood on a large area and could move and exhaust part of its destructive energy in the endless job of shaping the river bed itself;

now, flow is increased, and flood peaks exacerbated, while water and its transported sediments are carried with higher energy against new obstacles, like too narrow bridges, or bank protection works, or a factory, a building, a city, that are more easily damaged or destroyed.

Many countries have recognised the need for a radical switch in the policy of river management. Some, like USA and Netherlands, have started to dismantle protection works, like levees and weirs, or old dams. Many have recognised that the efforts undertaken to achieve *security-from-flooding* are a mere utopia; rather, we have to respect the very nature of rivers and learn how to *live together with the risk*, day by day, by activating smarter and effective mechanisms including endogenous financial schemes (like insurance systems), flood warning systems, temporary protection works and other technical solutions, as well as economic tools that may push for a different land use and efficient organization in disaster management[4].

The strong element that supports this policy switch is not an environmental one, in the sense of the nature-conservation argument based on existence value or other ethical reasons. It is basically a direct, economic cost-benefit consideration: the costs of the traditional engineering-based approach are not compensated by the benefits.

Here comes the idea that River Restoration, meant as a significant shift to more naturally-based balance between man and nature, is not only an environmental aim, but a powerful tool to achieve the safety-objective we all want to achieve.

Even if we demonstrate that a radical switch in the land-use and river management policy is the most cost-effective and efficient approach, it may be politically, socially and technically very hard to implement. Again, modifying consolidated practices and an incredibly diffused and heavily impacting land-use model implies unavoidably to look for a new trade-off amongst conflicting interests. Examples are municipalities that look for space, factories, cities, inhabitants that do not want to be flooded or damaged by a landslide, farmers that want to exploit every corner of land, environmentalists who do not want to give up with the last natural stretches where new retardation reservoirs or new roads are planned and the overall community (tax-payers) that does not want to waste so much of its budget in this endless and hopeless race for a stable water course.

Again, the challenge that basin authorities, administrators, practitioners, planners and designers, research community politicians and citizens are about to face is heavily demanding.

[4] This component seems to have played a major role, together with the scarce maintenance of levees, in the tragic recent event of New Orleans.

Figure 2. T. Lys (Gressoney, Italy), after the flood of 2002. Huge protection works along the banks are apparent, as is the dangerous proximity of the house to this aggressive water course (photo A. Goltara).

Water regional transfer

Italy is characterised by strong climatic differences. It may be spontaneous to think of transferring water from a region rich in water to a thirsty one. And Italy has significant examples: in particular, huge amounts of water are transferred from Basilicata region, rich in water, to Puglia region, extremely dry, but with a tremendously productive agriculture.

Water transfer, however, may carry profound environmental impacts by leaving donor rivers sadly naked and impoverishing subterranean aquifers; by altering local climate; by adding huge infrastructures in the territory (dams, canals, tunnels, pipes, pumping stations...). It also induces strong negative socio-economic impacts, as it inhibits current and potential activities in the donor region, puts on the shoulders of the local, regional and national community an additional economic burden to cover the investment, operation-management and replacement costs for very long time spans.

It may also create harsh social conflicts, as it may not be clear, for instance, to what extent should the water made available by one region, be paid by the other, particularly after long time since the works have been realised, or how much should be allocated to different regions and users during water stress situations.

Multipurpose Water management

Lake Como (or Lario), Lake Maggiore (or Verbano) and Lake Garda are natural lakes, regulated since several decades ago through small dams. There are also plenty of artificial water reservoirs spread in the country, most of them built for hydropower generation, or for irrigation purposes. Most of these reservoirs, are multipurpose, meaning that they serve multiple, different purposes; i.e. their management aims at different and, generally, conflicting objectives.

For instance, Lake Maggiore, which is a shared resource between Italy and Switzerland, is managed with the main objective of irrigation water supply for very important agricultural districts; but it also serves the hydropower generation through a system or run-of-river power stations downstream; another important objective is flood control on the lake shores; other objectives definitely not negligible are linked to low water levels, in particular the fulfilment of navigation requirements on the lake and aesthetic appearance of the lake (tourism); last but not the least, the management need to comply with the minimum vital flow requirement of the Ticino river emissary, one of the most beautiful Italian rivers for which a natural fluvial park has been created.

It is very common that in periods of flood risk, a claim is made that the reservoirs can and should be used to control floods; similar to the period of droughts, whose complaints are made because of a too little volume of stored water available. It is equally easily forgotten, however, that to control floods, the reservoir should be kept as empty as possible to be able to store the flood peak only when it comes (maybe once in 30, or even 200 years), while to satisfy water demand, it should be filled as much as possible particularly when any rainy season comes.

Again this is a typical problem of decision making with conflicting objecttives[5]. It is even more difficult than others, because an entire policy has to be decided, i.e. the complex rule with which the manager will regulate the lake every day (or minute or month, depending on the system dynamics) right now as well as in the future. The problem is even more difficult when more countries are involved.

After this brief overview, that reflects the Italian situation which is not peculiar only of Italy, it is worth asking what can be done to "manage conflicts in order to manage water". Basically, the same recommendations apply as for the international case.

[5] For a very detailed and innovative study leading to operational solutions, see Soncini-Sessa et al. (2003) and Soncini-Sessa (2004).

5. Recommendations

Improve decision making

Dealing with conflicts is an essential ingredient in environmental decision making, but one that still is practically overlooked and badly managed. Often public administrators, private enterprises and social action groups still do not know how to share information, points of view, needs, values, solution options and resources in an organized and constructive way. Public attempts confuse participation with one-way communication, leaving practically no room to any real interaction or feed back. Private enterprises try to avoid any contact with the local communities and the public in general, while deeply lobbying at any level; or they raise the job-loss ghost as a resource to split public opinion. Social groups assume extreme negative positions, mixing emotional reactions with rational arguments, which leads to unfruitful impasses and, at the same time, weakens their positions.

A better way of making decisions is not an optional tool, it rather looks as an unavoidable requisite to give a real content to the sustainability declarations: the "cost" of not improving/changing the way decisions are made is extremely high: public opposition, discontent, delays, additional economic costs, ineffectiveness, inefficiency. In particular, planning is either impossible, or useless because decisions made are then ignored. Without proper planning, no long-term rational and sustainable development path can be drawn (Green Cross Int., 1994).

Following the key issues to improve decision making in planning and management:

- *participation of stakeholders*: is to be organized and managed at both local and large scales. Local people, authorities, government representatives, research community, farmers, industrial groups, minority groups all need to be fully involved in the development of basin strategies, agreements and institutions. Stakeholders' and local community's representatives must be given an official and effective role in decision-making and implementation. Participation, in a broad sense, also includes looking for a balance between the State regulatory/control role and the (efficient) initiative of the private sector, while bringing local communities to full responsibility;
- *rationalization*: all the key steps that constitute a decision making process and that bring to a conceptualization of the decision problem at hand should be well linked from a logical point of view and made transparent and traceable;
- *integrated evaluation*: conceptual frameworks and applicable methods have to be developed for integrated evaluation (by unifying, as far as possible, the

common features of Cost-Benefit Analysis, Environmental Impact Assessment, Strategic Environmental Assessment, Multicriteria Analysis, and by coordinating in a logical way the additional information they provide) (UNESCO-GreenCross, 2002);

- *negotiation and conflict resolution*: much can be done to introduce more room for negotiation aimed at conflict resolution and foster its role before going to court or, even worse, start a real armed conflict. An important aspect is “sharing benefits rather than just water”: the focus of discussions on water cooperation should indeed be changed from simply sharing water, and restricting the freedom of each involved subject or their sovereignty in the transboundary case, to sharing the benefits that can be drawn from water, thus highlighting the myriad of benefits to be gained by all subjects (states) from the recognition of interdependence and integrated management both at a basin and aquifer level.
- *access to information and information gathering*: no participation or rationalization can be achieved if the basic information is not made accessible to all who have a voice to rise; this applies both at the local and at the international level. Gathering information may be extremely demanding and costly; too often the available information is outdated at the moment a decision is made. For these reasons, it is advisable to acquire updated and comprehensive information by exploiting also local, distributed information sources (e.g. local municipalities, or even local people) through better coordination and a system of incentives and sanctions.

Education and Capacity Building

Awareness raising and education strategies should be implemented to ensure that people learn how to best take up the challenges of sharing water. The cultural values related to water, environmental integrity, benefit sharing, cooperation should be cultivated very strongly. Only this background, a **new** (or improved[6]) **water culture**, can sustain a recovered vision of sustainable development and sustainable water management. This is the first step to modify behaviours, and achieve full responsibility and thus implement the “polluter/user pays” principle. In parallel, all subjects, and particularly public servants, should be trained to master new approaches, methods, techniques and, first of all, ideas and concepts, through well focused capacity building programmes.

An important point is directed to policy and decision makers: not only they should recognise the right and importance of public participation and consequently

[6] Sometimes it is just a matter of rehabilitating traditional practices so far abandoned for the sake of “progress”.

provide room for it, they should also learn how to behave in a participatory process. In fact, although the roles do not have to be confused, participation implies delegating some power and asks for a more real democratic attitude, beginning from the willingness to listen.

Environment and River Restoration

A river is not only "water regime", good water quality, plus a healthy instream ecosystem. A river moves, evolves, transports sediments, erodes and deposits, disperses water during flood peaks, disperses energy through a continuous modification of its river-bed, constantly communicates with subterranean aquifers, abates pollutants, and filtrate pollutant loads through a rich vegetation belt that also provides the backbone of an ecological network.

The awareness that such an holistic view is too often lacking, together with the recognition of the importance of preserving and recovering the global health of rivers, and water bodies in general (including lakes, wetlands, coastal zones, subterranean aquifers,...), if we want to achieve a sustainable water management, gave rise to a highly interdisciplinary field of applied research called River Restoration.

Its message is, in synthesis, that preserving or restoring and properly managing water bodies, and rivers in particular, and their associated territory is very important in order to comply with the sustainability paradigm.

One main reason stems from environmental issues, like nature and biodiversity conservation. Another reason is to provide the ground for a good quality of life in general, linked to recreation (aesthetics, wilderness,...) or socio-cultural dimension (man-water relationship; cultural heritage;...), considering that the demand for recreation in natural environments is high and increasing: considerable social benefits and potential economic returns are involved.

But another main reason stems from the economic-productive issue:

- well functioning ecosystems provide a fundamental base for economic-productive activities (e.g. by sustaining fishery, and ensuring good water quality)
- River Restoration can serve the purpose of combating flood and landsliding risk (as discussed previously in this paper)

River preservation/restoration, can be then viewed both as an objective in itself (nature conservation), and as a means to achieve socio-economic objectives (e.g. recreation) and even economic-productive objectives. Amongst them, safety rises in first position.

River restoration should, however, not be conceived as a mere exercise of aesthetic make-up to be undertaken only after main problems have been solved (flooding risk, water scarcity,...). Neither has it to be considered a kind of compensation against unsustainable policies. It rather is a pre-requisite for solving such main problems.

River restoration concepts may provide the key to face those situations of countries separated by a river, as already discussed. It is then recommended that a serious study is undertaken to set up shared river corridors (*espace de liberté*) for all such situations of post-conflict recovering countries as well for lucky situations of harmoniously co-existing countries.

International law

Efforts should be increased across the world to reach integrated and effective basin-wide and shared management agreements among all states in each international basin. States should ratify the 1997 UN Convention on the Non-Navigational Uses of International Watercourses.

The great challenge is to make existing instruments really effective. In all of the world's 263 international basins, joint management should be built on a system of effective inter-dependency; a pooling rather than a restriction of each nation's sovereignty, concentrating on sharing the many benefits and opportunities, which a good regional management of water will bring. Different national agendas within a basin must be recognized and common paths identified. There can be no unilateral solutions to essentially transboundary water problems. This is as true in the Middle East or West Africa as it is with the watercourses shared between the United States and its neighbours, or among the many nations of Europe.

It is also essential that water diversion and exploitation projects, in particular large hydropower schemes, are first assessed and discussed from the standpoint of the whole basin stakeholders, and not imposed unilaterally.

The centrality of capacity building and institution strengthening both in effective transboundary water management and in preventive hydro-diplomacy cannot be over-emphasised. Institution-building programs directed specifically to the world's international basins should contain:

- *Adaptable management structure.* Effective institutional management structures incorporate a certain level of flexibility, allowing for public input, changing basin priorities and new information and monitoring technologies.
- *Clear, fair and flexible criteria for water allocations and quality control.* A key concept, as already noted, is that of distributing *benefits from water use,* rather than just the *water itself.*
- *Detailed conflict resolution mechanisms.* Many basins continue to experience disputes even after a treaty is negotiated and signed. Thus, incorporating clear mechanisms for resolving conflicts is a prerequisite for effective, long-term basin management.

Examples can be taken from some long-standing water cooperation structures, such as the Danube Commission, the Rhine Commission, the Mekong River Commission, or the International Joint Commission (USA and Canada)[7].

Financial support

Interstate cooperation over transboundary watercourses and aquifers is an intensive process. In many regions of the developing world there is no infrastructure for even the simple exchange of data with neighbouring countries. International financial commitment is in this regard vital and should be increased, but it should be accompanied with an equivalent political commitment to share information and to look for better, joint, cooperative solutions. The creation of an International Shared Water Facility as a funding mechanism to support activities related to internationally shared water bodies has been recommended. This mechanism would help designing ad hoc strategies for each case to raise suitable funds and would provide incentives to those who actually do things, basing the incentive on results achieved, rather than just on declarations or facilities purchased or built to achieve such results. It should be a light structure, not a new concentration of financial resources like a bank; its philosophy would be to emphasise the use of resources that are endogenous to the countries involved in the particular case, while limiting as much as possible exogenous inputs. Indeed, we do not want poorer countries to fall into the "dependency-trap", and at the same time we do not want a new, highly costly, bureaucratic structure to be created. But we need enough resources to start the activation of endogenous, clever, and sustainable virtuous-cycles.

During the G8 Summit in Evian in June 2003, international organisations like The Global Water Partnership, Green Cross International, IUCN – The World Conservation Union, the International Network of Basin Organisations, the International Secretariat for Water, Programme Solidarité Eau, the World Water Council and the World Wide Fund for Nature, urged G8 world leaders to financially support the long term process of institutionalisation of transboundary water management and to allocate $1 billion during the next 10 years to finance interstate cooperation over this strategic issue. The appeal has been considered but the fund has not yet been released.

[7] Interesting initiatives put in action are for instance the following: The International Shared Aquifers Resources Management (launched at the initiative of UNESCO); The Global Environmental Facility (funding a large number of transboundary water projects); The Global International Water Assessment; WWF's transboundary river basin programmes; The IUCN Water and Nature Initiative; The UNESCO-Green Cross International "PC-CP: Water for Peace" programme; The European Union Water Initiative.

International mediation

In 1999, the World Commission on Water for the 21st Century invited four former heads of state and government, Mikhail Gorbachev, Fidel Ramos, Ketumile Masire and Ingvar Carlsson, to form a Sovereignty Panel to investigate the issue of National Sovereignty and International Watercourses under the coordination of Green Cross International. In January 2000, the Sovereignty Panel submitted its final report and specific recommendations to the World Commission, which were presented in a high-level debate during the 2nd World Water Forum in The Hague. One of the most important recommendations of the Sovereignty Panel and Green Cross International was the establishment of a "neutral International Forum and Ombudsman position for the identification, prevention, resolution and mediation of potential and actual international water conflicts". At the 2nd World Water Forum, a panel organised by Green Cross International, including Mikhail Gorbachev, Fidel Ramos, HRH the Prince of Orange, Ruud Lubbers and Ismail Seregeldin proposed the Creation of a Corps of Conflict Resolution Facilitators. These recommendations of the Sovereignty Panel and Green Cross International inspired the proposed creation of the Water Cooperation Facility. This international water cooperation facility should be a joint endeavour of the appropriate United Nations entities, an international legal institution and a water related international NGO. This mediation facility is envisaged to co-operate with the funding mechanism proposed and should be able to work with basin authorities, governments and other stakeholders to resolve particularly intractable water related disputes (Green Cross Int., 2000; UNESCO-Green Cross, 2002). The Cooperation Water Facility is now coordinated by UNESCO.

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PART II

CASE STUDIES

AN ECO-HYDROLOGICAL PROJECT ON TURKEY CREEK WATERSHED, SOUTH CAROLINA, U.S.A.

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Abstract. The low-gradient, forested wetland landscape of the southeastern United States' Coastal Plain represents an important eco-hydrologic system, yet there is a very little information available on the region's ecological, hydrological and biogeochemical processes. Long-term hydrologic monitoring can provide the information needed to understand basic hydrologic processes and their interactions with climatic variation, ecosystem processes, land use change, and other natural and anthropogenic disturbances. Monitoring also provides researchers with baseline data for evaluating responses, generating new scientific hypotheses, and testing eco-hydrologic models. This information is crucial for the sustainable management of present and future water resources in the southeastern Coastal Plain region, with its growing population, rapidly expanding development, and intensive timber and agricultural industries. This paper presents a multi-collaborative approach for building a monitoring and modeling framework for conducting long-term eco-hydrological studies on a 5,000 ha watershed in the South Carolina Coastal Plain.

Keywords: Low-gradient, Coastal plain, Forested wetlands, Water management, Water quality, Monitoring, Modeling, Francis Marion National Forest

1. Background

In 2004, with support from the USDA Forest Service (FS) Southern Research Station (SRS) and the National Council for Air and Stream Improvement, Inc.

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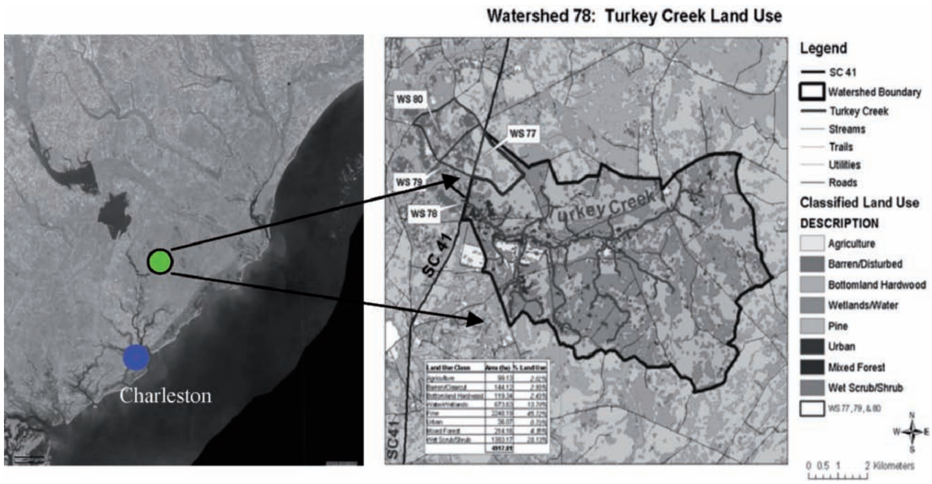

Figure 1. Coastal South Carolina and Charleston (left picture) with the location of the Turkey Creek Watershed (right picture).

(NCASI), a large-scale eco-hydrological monitoring and modeling study was re-established on a predominantly forested 5,000 ha coastal watershed at the Francis-Marion National Forest in South Carolina (Fig. 1). This revitalization effort is on the same watershed (WS 78) that was originally established by the Forest Service in 1964 and monitored until 1984 (Amatya and Trettin, 2007).

The current project includes the installation of a real-time gauging station (http://waterdata.usgs.gov/sc/nwis/uv?site_no=02172035) both for rainfall and flow (Fig. 2) on a newly constructed bridge, in cooperation with the United States Geological Survey (USGS), the College of Charleston, and the South Carolina Department of Transportation. Located at the headwaters of a major tributary of the Cooper River, which drains to the Charleston Harbor System, WS 78 is typical of other watersheds in the coastal plain where development is taking place.

The goal of this project is to develop a multi-cooperative research framework for addressing critical issues of sustainability of goods and environmental services from low-gradient forested wetland landscapes, which typify the coastal plain.

2. Current Objectives

- To study the stream flow dynamics and water balance of WS78;
- To explore the potential effects of depressional areas on wetland hydrologic functions;

Figure 2. USGS real time precipitation and flow gauging station (# 02172035) downstream (left picture) and stage recording sensor (right picture) upstream of Highway 41 bridge at Turkey Creek watershed.

- To evaluate the stream flow dynamics before and after a Category IV hurricane (Hurricane Hugo, 1989);
- To develop Total Maximum Daily Loads (TMDLs) for identified pollutants;
- To evaluate the spatial water table and soil moisture dynamics;
- To evaluate the stream water chemistry compared to other watersheds dominated by intensive plantations, agriculture and urban areas;
- To evaluate the stream biology and biological indicators of stream health;
- To study long-term hydrologic and water quality effects of land use change and land management practices including biomass removal and prescribed burning;
- To develop tools to communicate the values provided by healthy coastal watersheds.

3. Study Site

The third-order watershed WS 78 (e.g. Turkey Creek) with an approximate drainage area of 5,000 ha is located about 50 km north-west of Charleston, South Carolina (Fig. 1). The watershed monitoring was originally established in 1964 by installing a flow gauging station about 800 m downstream of the current gauging station. Land use within the watershed is comprised of 52% pine forest (mostly regenerated loblolly (Pinus taeda L.) and long leaf pine (Pinus palustris)), 28% wetland shrub and scrub land, 14% wetlands and water, and 6% in agricultural lands, roads and open areas (Amatya and Radecki-Pawlik, 2007). The watershed was heavily impacted by Hurricane Hugo in

September, 1989, and the forest canopy was almost completely destroyed (Hook et al., 1991). The watershed is dominated by poorly drained soils of Wahee (Clayey, mixed, thermic Aeric Ochraquults) and Lenoir (Clayey, mixed, Thermic Aeric Paleaquults) series followed by some sandy and loamy soils (SCS, 1980). The salient features of the watershed including the management practices and its recreational use are presented in Table 1.

TABLE 1. Salient Features of Turkey Creek Watershed (WS 78).

Salient Feature	Description
Location	Francis Marion National Forest near Huger, Berkeley County, South Carolina
Drainage area	~5,000 ha (50 km^2)
Hydrologic Unit	03050201
Gauging Location	WS 78 on SC Hwy 41 N (USGS Gauge # 02172035)
Datum of gage	~4.57m above sea level NGVD29
Latitude/Longitude	33°07'53" / 79°47'02" NAD27
Water and wetland areas	~670 ha (6.7 km^2)
Stream order and main stream length	Third order; 11.4 km
Elevation	3 to 12 m above mean sea level
Average annual rainfall	~1370 mm
Average annual temperature	~18.4℃
Average annual potential evapotranspiration:	~1000 mm
Average annual runoff	~330 mm
Tidal effects at the outlet	No tidal effects
Soils types	Poorly to moderately drained high water table soils
Major land use	Almost 94 percent on forest lands, public ownership
Forest types	Longleaf (*Pinus palustris*), and loblolly (*Pinus taeda L*), Bottomland hardwoods, Mixed pine-hardwood
Management practices	Planting and natural regeneration, biomass removal for reducing fire hazards, prescribed fire and thinning for restoration of native long leaf pine and habitat management for red-cockaded woodpeckers (*Picoides borealis*), an endangered species
Recreational uses	Hunting, fishing, bird watching, hiking, canoeing, historical tours, horse riding, all-terrain vehicle (ATV) trails

4. Approach

The most effective way to address scientific questions and management challenges relative to water resources is through collaborations among academia, industries, State and Federal government agencies, private landowners, and non-governmental organizations. Activities based on long-term monitoring capacity include projects to build and share a long-term eco-hydrological database, identify and prioritize new issues, conduct laboratory and field monitoring and modeling studies, and implement the recommended science and technology using appropriate science delivery approaches.

The monitoring approach includes initiation of measurements of basic eco-hydrological parameters such as precipitation, weather (air temperature, relative humidity, wind speed, and solar radiation), water quality (nutrients, physical and chemical parameters), and ground water table depths. Building upon this basic foundation, collaborative efforts will expand the scope and complexity by adding studies on mercury cycling, aquatic community composition and dynamics, carbon and green house gas fluxes, forest community and dynamics.

Similarly, Geographical Information Systems (GIS) based spatial data on topography, hydrography (drainage network), soils, vegetation, land use, and land management are being developed for the watershed. Spatial data based on a LIDAR (Light Detecting and Ranging) based technology will also be explored for accuracy and verification. A physically-based spatially distributed watershed eco-hydrologic model will be constructed using these data. The simulation model will be calibrated and validated using temporal and spatial data on precipitation, weather, stream flow rates, and ground water table for its application to evaluate management decisions related with anthropogenic and natural disturbances.

4.1. DEVELOPMENT OF THE COLLABORATIVE MONITORING PROGRAM

The Center for Forested Wetlands Research (CFWR) at Southern Research Station initiated the work by collaborating with Tetra-Tech, Inc., an Atlanta-based firm, in data sharing and database development. CFWR installed a Campbell Scientific CR10X complete weather station to monitor air temperature, humidity, wind speed, and solar radiation in the middle of the watershed (Fig. 3). The College of Charleston installed deep piezometers (Fig. 4) in December 2005 to assess surface-subsurface flow interactions. Stream water quality sampling station has recently been installed through a cooperative effort between the Forest Service CFWR and USGS (Fig. 5). Water samples are being analyzed for carbon and nutrients at the CFWR's Soil Chemistry laboratory in Charleston, South Carolina.

Multiple shallow water table wells have also been recently installed across the watershed in cooperation with the Francis Marion National Forest (FMNF) to examine rainfall-water table relationships and water table and soil moisture

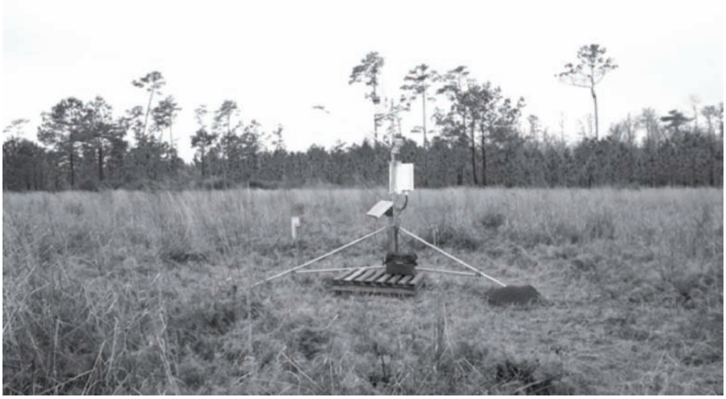

Figure 3. Campbell Scientific CR10X Weather station in the middle of the Turkey Creek watershed.

Figure 4. A set of deep piezometers near the weather station on the Turkey Creek watershed.

dynamics as affected by soil types and vegetation, and to validate models. Biologists at FMNF are planning to conduct monitoring for fish biota in the main stream and its tributaries.

There is also a growing interest in conducting research on Hg pollution in South Carolina coastal plain. Mercury in wet soils and wetlands has the potential to be converted into methyl-mercury, which through bioaccumulation through the food chain, may affect or even be lethal to fish and bird species. As the Turkey Creek watershed has a large area of wet soils and wetlands, the

Figure 5. ISCO water quality sampler (front) connected with the USGS real time rain/flow recording Sutton datalogger (back).

considerable potential for initiating a Hg cycling study is being explored with prospective collaborators.

5. Recent Studies on this and Adjacent Watersheds

Re-establishing the Turkey Creek Watershed as a gauging network on the 3rd order stream completes the establishment of 1st (WS 77 and WS 80), 2nd (WS 79) and 3rd (WS 78) order streams (Fig. 6) allowing researchers, land managers, and planners to evaluate the water budgets, effects of land use change or other disturbances on stream flow, nutrient export, and other ecological processes at multiple scales. Development of watershed hydrologic research on this and the adjacent smaller scale watersheds was outlined elsewhere (Amatya and Trettin, 2007). Long-term hydro-meteorologic data on the two first order watersheds (WS 77 and WS80) (Fig. 6) are made available for data sharing at *http://lterweb.forestry.oregonstate.edu/climhy/harvest.pl.*

A key factor in developing the large-scale watershed monitoring collaboration is the development and application of work at smaller scales. The following are accomplishments, which helped facilitate the development of work at the larger scale:

- Initial studies on stream flow dynamics of the watershed compared to two other adjacent 1st and 2nd order watersheds at Santee Experimental Forest (Fig. 6) using historical data have been conducted in collaboration with the Agricultural University of Krakow, Poland (Amatya and Radecki-Pawlik, 2007).

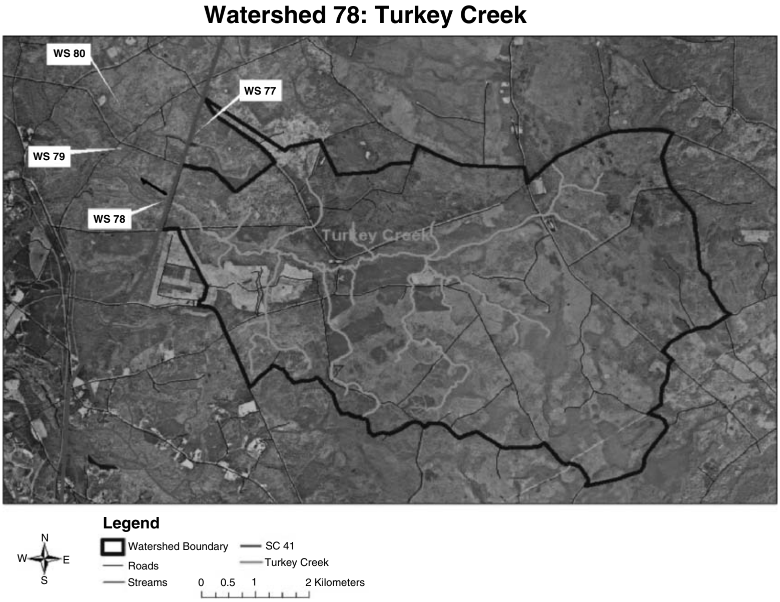

Figure 6. Layout of 1st (WS 77 and WS 80) and 2nd (WS 79) order watersheds within USDA Forest Service Santee Experimental Forest located adjacent to the 3rd (WS 78) Turkey Creek watershed.

- Harder et al. (2007a) recently reported a short-term water budget for an adjacent 1st order watershed (WS 80).
- Harder et al. (2007b) tested DRAINMOD (Skaggs, 1978) model on the 1st order watershed (WS 80) to further evaluate its long-term water budget.
- Wilson et al. (2007) reported effects of Hurricane Hugo in 1989 on the stream outflows and the nutrient exports of the WS 80.
- Other past studies prior to the year 2000 on the first-order watersheds are described by Amatya et al. (2005).

6. Ongoing Studies

- JJ&G Engineering and Tetra-Tech, Inc. are using historic data from the watersheds to develop a water quality model of the Charleston Harbor System for the Berkeley-Charleston-Dorchestor Council of Governments (Lu et al., 2005).
- A study on green house gas carbon dioxide (CO_2) and methane (CH_4) emissions from riparian wetlands of the watershed is currently ongoing (Fig. 7).

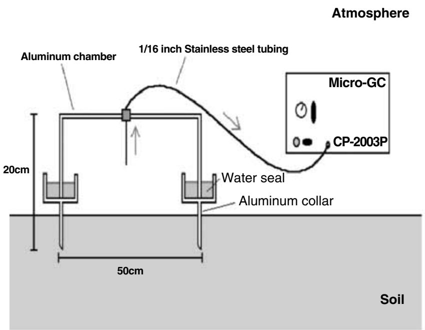

Figure 7. Schematic of a static chamber used to collect and measure trace gas fluxes (left) and the installation at the site (right) on Turkey Creek watershed.

- Another study evaluating the effects of depressional areas on wetland hydrologic functions is underway in cooperation with Florida A&M University.
- A study to examine the effects of biomass removal using thinning followed by prescribed burning both on a plot and a watershed-scale has just begun on the 1st (WS 77, WS80) and 2nd (WS 79) order watersheds (Fig. 6).
- Information on hydrology, meteorology, hydrogeology, geomorphology, topography, hydrography, soils, landuse, land and water management practices, stream water quality, and ecology are being prepared and analyzed together with watershed socio-economics for Turkey Creek basin management plan to be published in the second volume of the NATO/CCMS Integrated Water Management Pilot Workshop Science Series.

7. Planned Studies

- CFWR has initiated a collaboration with the Berkeley-Charleston-Dorchester County of Governments, Clemson University, and the College of Charleston for a potential Total Maximum Daily Load (TMDL) study on fecal coli form bacteria in a portion of the Turkey Creek stream.
- Collaborative efforts are underway to test and apply existing GIS-based distributed hydrologic models (SWAT (Arnold et al., 1998), DRAINWAT (Amatya et al., 1997; 2004)) to simulate the water budget, stream flows, surface and subsurface water yields, soil moisture, water table depth, and

nutrient and sediment loadings as affected by year-to-year variations in climate, as well as forest management practices including harvesting and prescribed fire.

8. Other Potential Collaborative Activities/Studies

Project collaborators have been meeting regularly about twice a year to review the progress and identify issues and funding sources to address them through collaborative studies. Examples of other works being considered, which demonstrate the value of a multi-institutional collaboration for large-scale eco-hydrologic monitoring include:

- Continuous monitoring of water quality for nutrients, sediment, and physical parameters (dissolved oxygen (DO), pH, temperature, turbidity, conductivity) and validation of stream water quality models;
- Monitoring for Hg and fecal coli form bacteria;
- Monitoring of tidal effects and salinity levels below the watershed outlet;
- Monitoring all or part of the Quinby Creek watershed adjacent (south) to Turkey Creek for the baseline data needed to evaluate planned developmental impacts;
- Surveys of Turkey Creek stream biology and morphology;
- Surveying for crayfish and freshwater mussels in wetlands within Turkey Creek and other areas in the region;
- LIDAR (Light Detection and Ranging) surveys of the Turkey Creek area for refining the watershed boundaries;
- Mapping of hydric soils and more recent land use/land cover;
- Analysis of pre- and post- Hurricane Hugo stream flow;
- Prediction of spatial distribution of moisture at various locations on the watershed;
- A more detailed water budget, including estimates of evapotranspiration;
- Cumulative effects of land management practices;

9. Benefits

Field studies and modeling applications will be an important resource for management decisions and monitoring assessments on the Francis Marion National Forest and other large tracts of forest land. They should also serve as reference eco-hydrologic units for comparison with more intensively managed forests and/or developed lands in the Coastal Plain, or for assessing allowable loading or discharge criteria. We hope that the historical and the new databases generated from studies on this watershed, including our long-term hydrologic research facilities at the Santee Experimental Forest, can increase the level of collaboration and our collective abilities to address many water resource issues facing the Southeastern United States and similar other regions around the world. With the watershed's location at the headwaters of the Cooper River and Charleston Harbor, the data collected will also be useful for evaluating additional water quality and quantity issues in downstream areas with tidal effects.

10. Research Collaborators

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INTEGRATED TRANSBOUNDARY MANAGEMENT OF LAKE CONSTANCE DRIVEN BY THE INTERNATIONAL COMMISSION FOR THE PROTECTION OF LAKE CONSTANCE (IGKB)

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Abstract. Lake management strategies must be based on sound scientific knowledge and are subject to constant changes. The International Commission for the Protection of Lake Constance (IGKB) is a good example of a successful international commission which acts on a broad consensus amongst the many interests and users around Lake Constance. As such, eutrophication was successfully battled, and nowadays integral water protection, including qualitative, quantitative and morphological aspects, is performed. This reflects a new philosophy and conception of nature and environmental protection.

Keywords: Lake Constance; lake management; monitoring; integral water protection; transboundary; transdisciplinary; eutrophication; catchment approach; ecosystem integrity

1. Introduction

Integrated transboundary lake catchment management and integrated transboundary river basin management are widely accepted nowadays and basically

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supported by sound scientific concepts in aquatic and landscape ecology (Cooke et al., 1993; Boon, 2005). In particular, lakes are strongly dependent on their catchment and external load by tributaries and diffuse sources. The most difficult part of integrated water management, however, is clearly the implementation of measures as ever existing conflicts of users and protectors interests must be solved (Bloesch, 2005). Therefore, an intensive exchange of opinions between scientists, experts, managers and decision makers (politicians) must take place. Only applied and transdisciplinary procedures can lead to successful solutions supporting "sustainable" use of our water resources and aquatic ecosystems.

This paper demonstrates a successful example of integrated and transboundary lake management that tackled eutrophication in the 1970s until today. However, many problems remain or emerge that still need to be solved in a continuous effort as outlined in the conclusions.

2. Case Study Description and the Decisional Problem

Lake Constance is the second largest prealpine European lake by area and volume. The lake basin is situated in the Molasse basin of the northern Alpine foreland and was mainly formed by water and ice activity during the last Quaternary glaciation period more than 15,000 years ago. The catchment area of about 11,000 km² (~20 times the lake surface) covers the territories of the four European countries Germany (28%), Switzerland with Liechtenstein (48%) and Austria (24%) (Figure 1). Lake Constance is traditionally divided into western Lower Lake Constance and eastern Upper Lake Constance. More than 75% of the water inflow originates from the Alps mainly by the tributaries Alpenrhein and Bregenzerach in the eastern part of the Upper Lake.

Lake Constance is oriented from Northwest to Southeast and the water body is strongly influenced by wind-activity mostly from western and southern directions. It is an oligo-mesotrophic hard water lake with biogenic calcite precipitation. Electrical conductivity of the water typically ranges between 260 and 300 μS/cm². Morphometric and chemical data on Lake Constance are compiled in Tables 1 and 2.

The phytoplankton succession typically shows a spring bloom followed by the "clear water" phase with very low phytoplankton abundance due to zooplankton grazing. During the rest of the year, phytoplankton dynamics is moderate. Diatoms contribute up to 90% of the phytoplankton bio-volume in spring and approximately 5% during the "clear water" phase. Phytoplankton, bacteria and crustaceans are the most important contributors of biomass in Lake Constance. While copepods dominate the zooplankton in winter, cladocerans are abundant in spring and summer. Protozoa and rotifers are distinct but less important

Figure 1. Lake Constance and its catchment. The main tributary is the Alpine Rhine (Alpenrhein).

members of the zooplankton community. About 30 species of fish contribute to the fauna of Lake Constance. The dominant species are whitefish (*Coregonus lavaretus* L.) and perch (*Perca fluviatlis* L.). During summer, zooplankton is the main food source for most fish in Lake Constance.

TABLE 1. Morphometric data of Lake Constance (47°39'N, 9° 18'E) and its catchment area.

	Upper lake	Lower lake	total
Altitude a.s.l (m) at middle water level	395.45	395.26	–
Surface area of water (km^2)	472.96	62.92	535.88
Volume ($10^9 m^3$)	47.637	0.810	48.49
Maximum depth (m)	254	46	–
Mean depth (m)	95	11	90.5
Mean range of annual water level fluctuation (m)	1.50	1.48	–
Length of shoreline (km)	186	87	273
Mean outflow ($10^9 m^3$/yr)	11.1	11.7	11.7
Residence time (yr)	4.3	(0.07)	–
Catchment area (km^2)	10,919	568	11,487

There are numerous detailed and long-term data available on Lake Constance and its catchment that can be statistically analyzed and interpreted (e.g. Bäuerle & Gaedke 1998 and Böger 1998; reports quoted in IGKB 2004a).

TABLE 2. Main chemical water constituents in Lake Constance (modified after Stabel 1998).

	mg/l	mol/l
Ca^{2+}	36.1 – 56.1	$0.9 - 1.4 \times 10^{-3}$
Mg^{2+}	4.9 – 9.0	$0.2 - 0.37 \times 10^{-3}$
Na^{+}	3.4 – 4.6	$0.15 - 0.2 \times 10^{-3}$
K^{-}	1.0 – 1.3	$0.26 - 0.33 \times 10^{-4}$
Sr^{2+}	0.39 – 0.48	$4.4 - 5.4 \times 10^{-6}$
HCO_3^{-}	142.2 – 155.6	$1.68 - 2.55 \times 10^{-3}$
SO_4^{2-}	31.0 – 35.5	$0.32 - 0.36 \times 10^{-3}$
Cl^{-}	4.8 – 5.9	$0.13 - 0.16 \times 10^{-3}$
NO_3^{-}	3.4 – 4.8	$0.5 - 0.7 \times 10^{-4}$
Total P	0.01	0.32×10^{-6}

2.1 EUTROPHICATION – THE GREAT PROBLEM IN THE 1960S AND 1970S

Lake eutrophication was the top issue of water management in the past 40 years. Hence, in the applied work of IGKB, particularly phosphorus, the nutrient limiting algal growth, played a key role. In developing lake models a critical phosphorus input load could be defined for any lake (e.g. Vollenweider 1976). This load is approximately 200 tons of bioavailable phosphorus per year for Lake Constance (Bührer 2002). The best strategy in lake restoration is fighting the causes rather than fighting the effects. Thus, firstly external measures should be implemented, i.e. reducing point and non-point sources of phosphorus (and contaminants). If this is not sufficient because the tolerable P input limit cannot be achieved, lake internal measures may be realized, such as aeration by oxygen and air, or sealing of lake sediments. However, this applies mostly to smaller and shallower lakes situated in catchments extensively used by agriculture.

The objective to be achieved was clearly the protection of Lake Constance in view of the large reservoir for drinking water supply (e.g. the station in Sipplingen, supplying about four million people). Later, more ecological objectives were perceived, for example the protection of the lake ecosystem in terms of healthy fish populations and near-natural littoral zones as tourist attraction.

2.2 TRANSBOUNDARY LAKE MANAGEMENT AND MONITORING THROUGH VARIOUS ORGANIZATIONS

Schröder (2004) describes in detail the international organizations involved in transboundary water management of Lake Constance, and their information strategies. A key role has the International Commission for the Protection of Lake Constance (IGKB), founded in 1959, which elaborates recommendations for the riparian national governments of Germany, Austria and Switzerland to implement measures for lake protection. Since monitoring is closely linked with, and part of, water management, the IGKB is coordinating transboundary water quality survey programmes. The IGKB works on consensus and produces sound scientifically based guidelines. Achievements and outlook are summarized in IGKB (2004a). The organization scheme (Figure 2) shows the different working units and their tasks. It is important to note that projects such as the 2004-2009 Action Programme are linked to any of the three organizational units, and that the "bone work" is performed within the expert groups. The recommendations given by the Commission are aimed at supporting the national legislative and political forces to implement and coordinate the respective laws and regulations for water protection, and to strengthen public awareness. A pamphlet "Seespiegel" is published twice a year, and information is also available in the internet homepage (http://www.igkb.org and http://www.seespiegel.de).

Figure 2. Organizational structure of IGKB.

IGKB is devoted to sustainable development, and is clearly respecting any interests for protection and use of lake water and landscape. There is close contact and exchange between social, political and legislative demands, and scientific knowledge and research results, which is ultimately needed to find practical solutions of emerging environmental problems. Hence, the working strategy of IGKB is not to develop theoretically based measures in the narrow perspective of the scientific "ivory tower", but to achieve applied, practicable solutions that are elaborated in unbureaucratic co-operation and can be confirmed in round table discussions with regional and local user groups and institutions, such as farmer's organizations, public water supply, fishery clubs, nature protection associations (NGOs), ship-owner companies, tourist offices, etc.

The most important international actors in IGKB co-operation are:

- The International Conference of Deputies for Fishery in Lake Constance (IBKF, est. 1893),
- The Syndicate of the Waterworks in the region Lake Constance-Rhine (AWBR, est. 1968),
- The International Conference of Heads of Governments (IBK, est. 1972),
- The International Navigation Commission for Lake Constance (ISKB, est. 1973), and
- The International Lake Constance Foundation (Bodensee-Stiftung, est. 1994 by six NGOs (http://www.bodensee-stiftung.org).

The secret of efficiency and success certainly is the fact that the riparian countries respect *de facto* a supranational free pelagic water zone (so-called "condominium") similar to that realized and justified by international law in the oceans. This unique situation of "no borderlines" across the lake reflects the strong regional identification of residents with their Lake Constance Region.

3. Methods and Results

For Lake Constance the IGKB decided to reduce P input by intense waste water treatment. Figure 3 illustrates the success in the strategy of technical waste water treatment (and a phosphorus ban in detergents, implemented in 1986) in the catchment of Lake Constance. The exponential increase in both phosphorus load and concentration, experienced between 1951 (7 μg/l total P in the lake water) and 1979 (87 μg/l total P) due to the increasing population pressure in the catchment could be turned into a similarly dramatic decrease between 1980 and 2004 (10 μg/l total P). Following the phosphorus peaks of tributaries, lake water and lake sediments, it is interesting to note that the water concentration has a responding time lag to reduced input of approximately seven years, while the sediments' "memory" holds for about 20-30 years. Hence, phosphorus sedimentation, retention and internal loading out of bottom sediments are key factors in lake metabolism (Wehrli & Wüest 1996). Similar successful results have been obtained in many other lakes, demonstrating the function of this cause-effect relationship (Ambühl & Bührer 1993).

In contrast to phosphorus, nitrogen concentrations in Lake Constance increased from 1963 (0.5 mg/l NO_3 –N) to 1987 (1 mg/l NO_3 –N) and thereafter remained almost stable until today (2004: 0.9 mg/l NO_3 –N). We note that the changing N:P ratios are of ecological importance for competing algae, and excessive nitrogen in the River Rhine (outlet of Lake Constance) may ultimately enhance eutrophication in the North Sea as final recipient, where nitrogen instead of phosphorus is limiting algal growth. Therefore, international N reduction programmes are in progress. These qualitative problems of pollution, combated by technical measures, have been partly solved by industrialized countries, but are still a major issue in transitional and developing countries (Bloesch 2005). The more point sources are eliminated or diminished, the more important become diffuse sources originating basically in agricultural land by excessive use of fertilizers and pesticides.

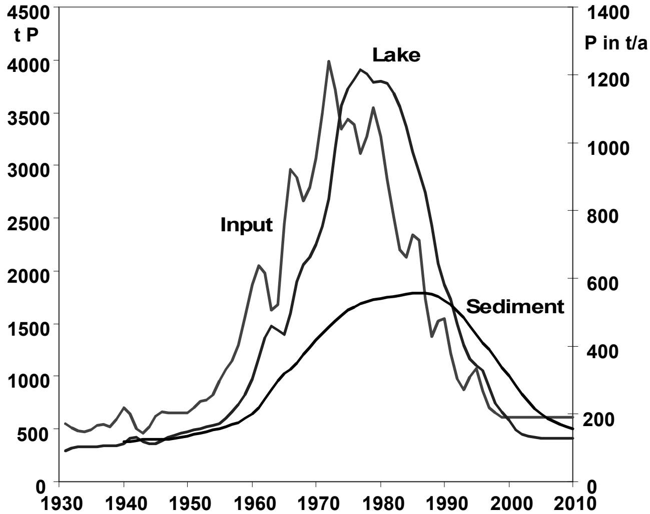

Figure 3. Phosphorus input (P in t/a) and content (t P) in Lake Constance tributaries, pelagic waters and sediments, according to the two box model of BÜHRER (2002).

3.1 NEW LAKE MANAGEMENT ISSUES IN THE 21ST CENTURY – INTEGRATIVE WATER PROTECTION

More recently, heavy metals, persistent organic chemicals and/or hormone active substances have been recognized as causing biological hazards in the sub-lethal and long-term range (Fischnetz 2004). These substances may enter the food chain and affect human health. From the management perspective, emission and immission standards, the prevention of pollution at its source, the promotion of reuse and recycling of chemicals in households and industrial production, and the principle of precaution should be strongly considered and be founded in the respective water protection laws.

Lake management strategies in general must be founded on basic limnological research, i.e. on the knowledge of the functioning of lake ecosystems (Cooke et al., 1993). Through the trophic cascade, nutrients influence phytoplankton, zooplankton and fish (Carpenter 1988). Certainly, the reduction of nutrients to manipulate algal biomass turned out to be successful, although primary production may remain high, and biomass, strongly fluctuating, may show only a slow reaction. In contrast, biomanipulation of whole lakes to reduce algal biomass by top down regulation was rather problematic or ineffective. Predictive biological models are not easy to achieve because of the great complexity of planktonic communities (Edmondson 1979). The scientific debate is on whether there is bottom up (by nutrients) or top down (by predators) control of algae and biomass. Many experimental results showed that both mechanisms are effective and quite often balanced on the long-term (Bloesch & Bürgi 1989). If, by all means, the fish community is changed, we end up not only in scientifically interesting topics such as natural reproduction and survival strategies, but also in applied problems of fish yield (commercial fishery). The cycle from applied problems to basic system knowledge is closed.

In the past decades, old views and a sectional, one dimensional water protection have been gradually replaced by a new strategy: Modern integral (multidimensional) water protection is composed of three aspects, the qualitative, quantitative and morphological water protection (Table 3). Phosphorus load and concentration (eutrophication) are not the only problems with regard to lake protection. For instance, many large lakes are regulated for flood control. However, the fact that the water level of Lake Constance is not regulated ensures some wetlands along flat shores that are habitats of rare plant species (e.g. forget-me-not *Myosotis Rehsteineri*). The morphological destruction of lake shores and shallow water zones by walls, dikes and harbours further deteriorates littoral ecosystems that are important e.g. for fish reproduction and fishery. Almost half of the littoral zones of Lake Constance are modified by morphological destructions (IGKB 2004a). The ultimate goal of integral water protection is to ensure the ecological integrity of surface and ground waters as stipulated, e.g. in the revised Swiss Federal Law for Water Protection (1991) and as requested by the EU-Water Framework Directive (2000).

The three aspects of integral water protection are interconnected with ecosystems and user topics similarly to the network of integral ecosystems (Figure 4), demonstrating that sectional thinking can never yield good solutions. If we solve one particular problem, we may create two new problems elsewhere in the system. Integral water protection in general (and Lake Constance protection in particular) needs to be viewed in context with water use, such as drinking water supply and recreation. While the first addresses mainly the qualitative and to lesser extent the quantitative aspects of water protection, the latter addresses morphological aspects as well. In view of ecosystem function, it is important to stress the catchment approach, as the lake is influenced not only by lake internal impacts, but also by lake external impacts, as shown above. The morphological integrity of shores (macrophyte and fish habitats) and the connectivity of tributaries play an extremely important ecological role as specific ecotones and hence for plant and animal life. The running waters must not be excluded from the lake's perspective.

Species protection (as referred to the red lists of endangered species) should not be based on particular needs of single species, but rather should be based on complete habitat protection. In summary, we need to solve the conflicts of the

TABLE 3. Integral water protection: contents and principles. Normal type reflects user's points, italic type reflects subsequent ecological points, conclusions for future strategies in bold type.

Qualitative Water Protection (Water quality)	Quantitative Water Protection (Water quantity, Water cycle)	Morphological Water Protection (Space and Morphology of surface waters)
dissolution is no solution (emission and immission control)	lake regulation, water abstraction for hydropower and irrigation	growing human population demands more land
90-95% of population are connected to waste water treatment plants	water diversion into different catchments, excessive groundwater exploitation	human health demands melioration of wetlands
high costs (in Switzerland ca. 40 billion Swiss Francs)	in Switzerland: ~60% of energy production stems from hydropower	humans need lakes and rivers for navigation
load reduction stops pollution and eutrophication	hydropower is sustainable (no CO_2 production)	human welfare demands water protection
but: treatment is selective (heavy metals accumulate in sludge and organic contaminants pass the plant)	*but: lake level regulation eliminates nearshore wetlands, streams and rivers with no residual water are drying out*	*but: lake shores are destroyed, streams and rivers are channelized*
but: non-point sources are still effective	*but: natural flow regime and sediment transportation are disturbed*	*but: connectivity and ecological function are disturbed*
but: fighting effects rather than source of pollution	*but: fish and benthos communities are disturbed*	*but: habitats are destroyed and biodiversity is reduced*
end-of-pipe solutions must be replaced by recycling strategies	**renewable energy (water) vs. aquatic ecosystems (waters) must be balanced**	**technical approach is strong, but nature is stronger**

various interests, and both water/lake protection and use should be balanced, i.e. the principle of sustainable use, now generally accepted since the Conference of Rio (1992), should be fulfilled. Therefore, in 2004, the IGKB decided to launch a five years "action programme" emphasizing on the rehabilitation of shore areas along Lake Constance (IGKB 2004b). The philosophical background of integral water protection is a new understanding of the technical progress and nature, best illustrated by Capra (1995) and summarized in Table 4.

The Cartesian view of technology and nature (being a whore dominated by man) is changed into a partnership between nature and man (who is ultimately part of nature). This approach also includes the holistic view that (eco)systems must not be considered machines that can be technically repaired. The idealistic, romantic picture of nature as being beautiful is completed by its brutal counterpart (floods, eruptions of volcanoes, earthquakes, etc). Its dynamic is accepted, including the outbalance of extremes and the disturbance of stable equilibriums. Hence, nature protection is rather allowance for stochastic changes than

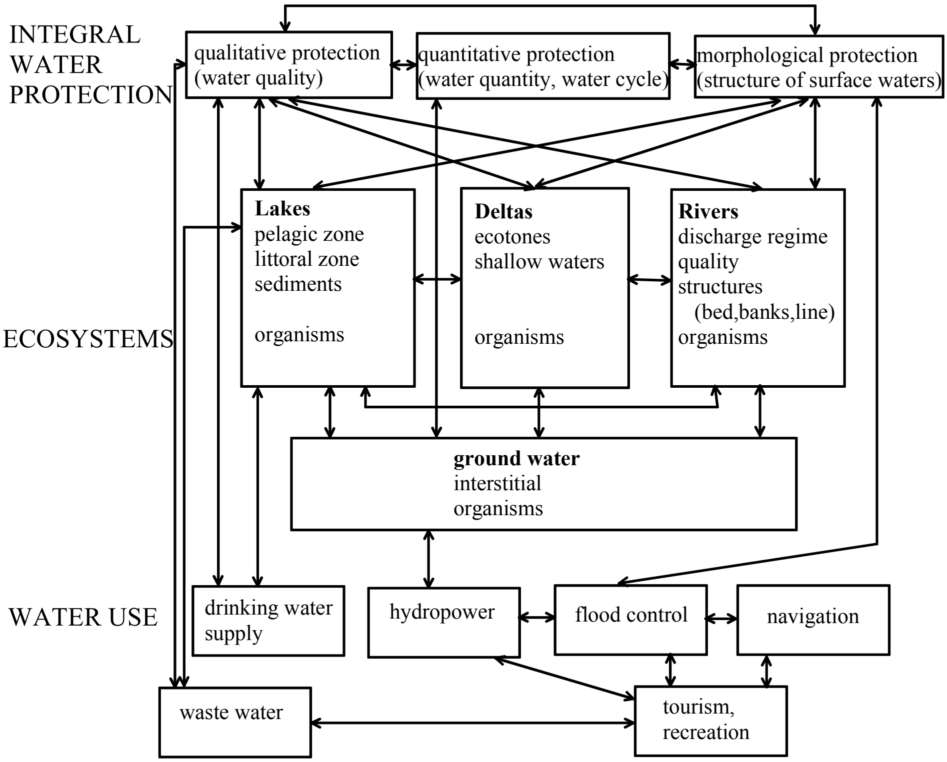

Figure 4. Complex network of integral water protection, ecosystems and water use. For comparison see trophic relationship in ecosystems, e.g. in textbooks (Moss 1992).

conservation in the traditional way. These ideas focus into a realistic strategy of balancing water use and water protection (Table 5).

TABLE 4. Opposing key words representing the old and new philosophy in understanding nature and hence integral water protection. Compiled after Capra (1995), further explanations in text.

OLD PHILOSOPHY	NEW PHILOSOPHY
One aspect	Combination of aspects
One dimension	Multi-dimensions
Linear	Complex
Machine	System
Technology	Spirit
Water used as transport vehicle	Waters understood as ecosystems
Water use is superior	Balance of interests

TABLE 5. Proposals for sustainable development and integrated water protection. The ultimate goal is to implement the ecological functionality of surface and ground waters in view of the natural water cycle (catchment approach).

Topics for sustainable development (integrated water protection)
Modern concepts of urban water management
Further improvement of waste water treatment technology (organic compounds)
New industrial production strategies
Extensive ecologically sound agricultural practices
Landscape planning, separating distinct zones for various users
Natural reserve conservation
Lake shore and stream habitat and riparian restoration
Enhancing connectivity and biodiversity
Including humans for “soft” recreational use of waters

4. Conclusions and Future Developments

The transboundary management strategy of Lake Constance proved to be successful in many ways: (1) The reduction of nutrient input by establishing waste water treatment plant is the most important measure to fight eutrophication (only if this is not sufficient lake internal measures must be considered, which, however, was not the case for Lake Constance); (2) The joint cooperation between three states by establishing an international commission with experts ensures scientifically sound proposals that can be implemented jointly by the states governments after political dispute; (3) By further developing the philosophy of lake management, ecological aspects can be considered in the conflict of interest of various user groups.

Despite of the successful tackling of eutrophication, water protection and management are not finished by having established waste water treatment plants. These need a continuous technical maintenance and adjustment in order to keep them functional. Only with these efforts we can manage to keep phosphorus concentrations at the present low level. Problems into the future are mitigating the diffuse sources (mainly from agriculture) and the "chemical cocktails" still released by human activity that pass waste water treatment plants and threaten biota (fish in particular, by heavy metal accumulation or endocrine disruptors that change sexes and decrease fertility; Fischnetz 2004). It must be stressed that the principle "fighting the source rather than the effect" is still valid and must be the political guideline into the future.

Further in-lake problems will be: the increasing introduction and appearance of neozoans and neophytes (having controlled the invasion of the mussel *Dreissena polymorpha* PALL.), the debated role of fish hatcheries and inbreeding threatening native populations (about 60% of the whitefish originate from hatcheries), and the sediment load of major tributaries like Alpenrhein, Argen and Schussen (we do not know much about the fate of the fine fraction of 1-4 mm). In particular, the channelized river mouths need a thorough restoration in order to restore the deltas and their ecological function.

The demographic pressure in the catchment is increasing and hence the threat of the whole lake ecosystem. Traffic (road construction plans) and ongoing land use and development may further increase morphological destruction of shores despite of ongoing local restoration projects. In summary, integrated lake management must stress ecological functions and balance them against social and economic demands.

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INTEGRATED WATER MANAGEMENT IN THE SEVEN CITIES BASIN

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Abstract. The Sete Cidades lake in the Azores, is located in a volcanic crater. Increased frequency of logging (380 hectares of production forests) and the use of fertilizers on pastures and forages (450 hectares) that sustain 750 cows, provide direct employment to 67 farmers and induce employment to more 50 actives, but also increases the eutrophycation and sedimentation of the lake. To address the issue an integrated model generates efficient land use scenarios for different degrees of phosphorus emissions with related effects in the water quality. The model is used to obtain various indicators for each scenario that feed a multi-objective program able to find the dominant solutions. The final solution is chosen by the politicians: 600 cows that produce 3.0 millions of milk, provide direct employment to 55 farmers and induce employment to more 41 actives. This, jointly with a partial stream deviation, allows a reduction of 63% of the phosphorus load to the lake. Compensatory measures pay the farmers their losses and compensate the community for the lost employment.

Keywords: integrated water management; decision support system; Azores

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1. Introduction

Water can be produced, transported and distributed by the environment, by diffused land users or by institutions that manage pipes and reservoirs. The prevailing idea is that integrated water management must be done by institutions able to control all the water in the watershed, and the easiest way to think and do that it is to store the water into reservoirs and to distribute it through pipes.

Meanwhile the role of the environment and land users in integrated water management turns to be assumed either as an environmental fatality or as land user nuisances. Even in terms of modelling there is an inadequate representation of land users' decisions in integrated water management plans (Bazzani, 2005). Nevertheless some recent work has tried to overcome this limitation through the design of a DSS that simulates the economically driven decision processes of land users (Bazzani et al., 2005).

In line with this perspective, and to address the eutrophycation problem of Sete Cidades lake in the Azores, three integrated models (agro-environmental, environmental and economic) are designed to generate efficient land use for more than seven scenarios associated with different degrees of phosphorus emissions. Each one of these plus seven environmental scenarios is associated with different results in the water quality of the lake and with four alternatives of compensatory measures for the farmers and for the community, leading to 29 complete scenarios.

The combination of the three models allows the consistent estimation of various indicators for each scenario. Then a multiobjective program is used to get acceptable weights for each indicator by the stakeholders. The dominant solutions are selected and finally a solution is discussed.

2. Case Study Description and the Decision Problem

The Sete Cidades Lake (437 hectares) is located in the volcanic crater of the São Miguel Island (Azores). The watershed has 1923 hectares, which 25% is covered with water. The remaining areas are pastures (450 hectares), production forests (380 hectares), wild forests (450 hectares) and others, including social areas (160 hectares). Precipitation is 1600 mm *per* year. Extreme logging and the use of fertilisers in the pastures increased sedimentation and eutrophycation of the water body.

Since the problem was highlighted in the nineties, the regional government undertook a series of measures: land use planning without taking into account the social and economic effects and reactions; introduction of fish to remove the phosphorous and introduction of algae to protect the fish; removal of dead algae to clean the lake with a special boat; attempt to buy the milk quota from the farmers; attempt to introduce agro-environmental measures without appropriate calibration. Unfortunately none of these measures were effective.

The problem seems to be that those policies never tried to understand the behaviour of the stakeholders. Farmers have 750 cows which produce 3.8 millions of milk per year, provide direct employment to 67 farmers and induce employment to more 50 actives. They sustain 400 persons which represent half of the population of the watershed. On the other hand, these 750 cows generate 600 Kg of phosphorus *per* year which leads to an increased degradation of the lagoon, probably to a reduction of 15% in tourism (Dentinho et al., 2000) and to negative effects on employment outside the basin of around 250 employees. Intensified dairy production has successively resulted in depletion of the lakes mainly due to unsustainable farming and logging practices. Nevertheless the issue became a public issue when eutrophycation and sedimentation increased strongly in the two of the major lakes in S. Miguel Island that have the greater attraction for tourists.

Figure 1 presents the current situation of the Sete Cidades Basin. The land is currently used for intensive dairy farming, which results in deforestation, soil erosion and sedimentation of the lake. The soil erosion increases the flow of nutrients and fertilizers in the Lake which contributes directly to eutrophycation. Until now, the increased sedimentation has resulted in a decrease of the depth

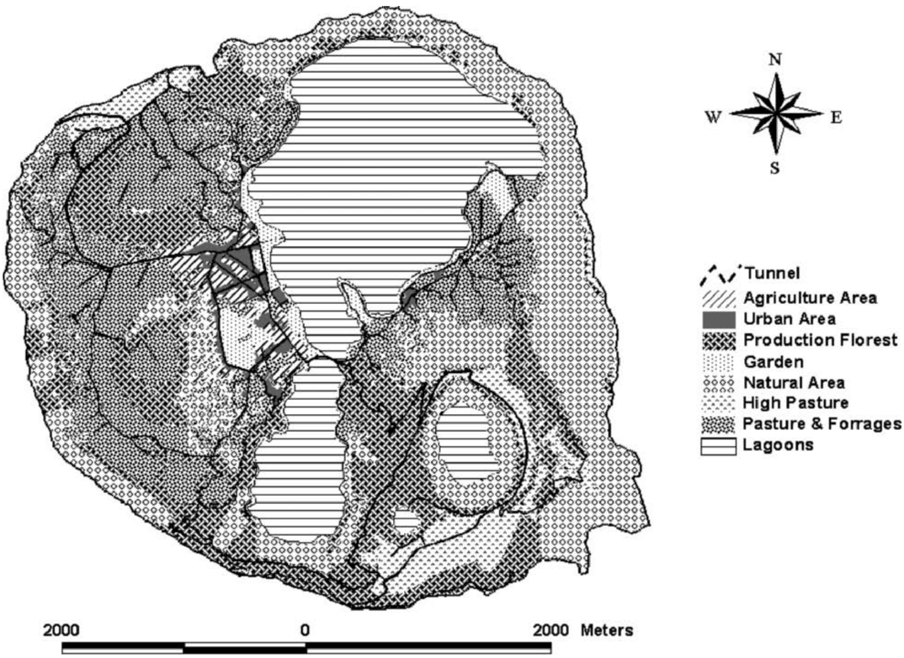

Figure 1. Current land use of Seven Cities Basin

of the lake by 10 meters. Continued sedimentation and eutrophycation will have two major impacts: 1) degradation of the landscape aesthetics and; 2) reduced water quality and availability.

The water flow of the basin is 14 million cubic meters per year. The renovation rate of the lake is 20% per year, which leads to an average time for renovation of five years. The average quality of the lake water measured by the Carlson Indicator of the Trophic State(CTS = 40-50), assessed by the transparency of the water, the concentration of phosphorus or the concentration of chlorophyll, shows a situation that varies between mesotrophy and meso-eutrophy along the last 10 years. Physical and chemical analysis of the various sub-basins show a close relation between the concentration of phosphorus and nitrogen, the distribution of cattle, and the functioning of the drainage and precipitation systems.

3. Methods

To address this problem (see Figure 2) we identify consistent scenarios and then evaluate them with a multicriteria analytical tool (Bana e Costa, C. et al., 2002). To obtain consistent scenarios, we formulate, calibrate and integrate three models: an environmental model of the lagoon, an agro-environmental model of the basin and an economic model of the village. To evaluate all the scenarios we use a decision support system and select three dominant scenarios based on twelve economic and environmental criteria.

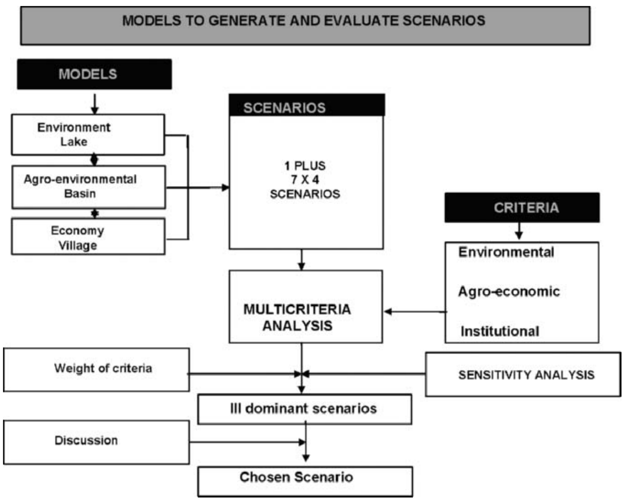

Figure 2. Method to Generate and Evaluate Scenarios

The various scenarios result from the combination of four types of policies:

- Preventive measures are related to changes on land use and defined according to the effect on the emissions to the lagoon.
- Corrective measures involve the deviation of the polluted water to outside the basin and can also be associated with changes in the emissions to the lagoon.
- Social measures are due to compensate the loss of employment in the village that results from the changes imposed on land use.
- And economic measures aimed to compensate the loss of income by the farmers due to changes imposed in the land use.

Table 1 presents the 29 scenarios associated with the combination of the measures described above and their effect on the reduction of emissions that reach the lagoon. These scenarios result from the combination of seven environmental alternatives with four alternatives for compensatory policies: a) yes or no to compensate the farmers from income loss; and b) yes or no to compensate the local community from direct and induced decrease in local employment.

The seven environmental scenarios are derived from the combination of corrective measures with preventive measures. The corrective measure taken into account is the construction of a tube to derive 25% of the polluted water from the fields to outside the basin through a discharger tunnel. The preventive measure is the reduction of 25%, 50% or 75% of phosphorus emissions. The 29th scenario is the existent situation.

TABLE 1. Effect of the different scenarios from emissions to the lake

Combined Effect		**Preventive measures - effect on reduction of emissions**							
		0%		25%		50%		75%	
Corrective Measures Effects on reduction of emissions	0%	0%		25%	25%	50%	50%	75%	75%
				25%	25%	50%	50%	75%	75%
	25%	25%	25%	44%	44%	63%	63%	83%	83%
		25%	25%	44%	44%	63%	63%	83%	83%

No compensation	**Economic compensation**
Social compensation	**Socio/Economic compensation**

To estimate the effects of those scenarios on other environmental and economic indicators we need to formulate, calibrate and simulate the environmental model of the lake, the agro-environmental model of the basin and the economic model of the village.

The environmental model of the lake is an adaptation of the model used by AquaSense Grontmi to the conditions of the Sete Cidades Lake. The model is calibrated based on data about the level of phosphate in the lake and phosphate emissions collected in the small streams that reach the lagoon, which accounts for an annual inflow of phosphorus of around 600 Kg per year.

The major problem related to water quality is the growth of cianobacteria and other phytoplankton that, during summer, are responsible for changes in the colour of the lake. It is the inflow of phosphate to the lake and the seasonal changes in the weather conditions that are responsible for the growth of cianobacteria and other phytoplankton, during summer, in Sete Cidades lake. Notice that the concentration of phosphorus is acceptable when compared with other lake systems.

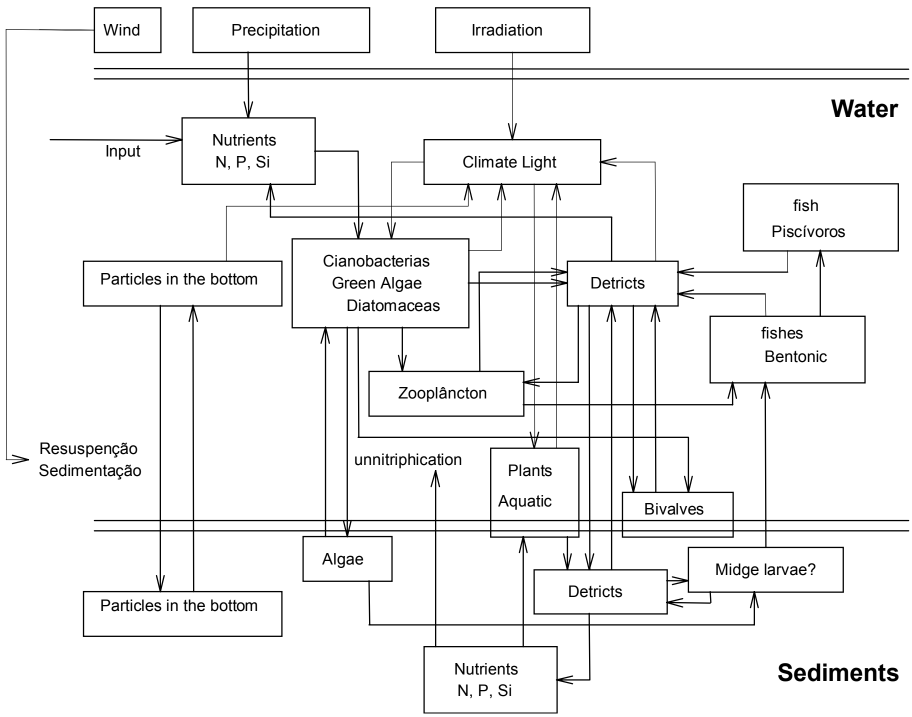

Figure 3. Environmental Model applied to Sete Cidades Lake

The adaptation of the Model used by AquaSense Grontmi (http://www.grontmij.com/) is made by dividing the Sete Cidades lake in three dimension cells. Then, based on the inflow of phosphorus and nitrogen, it is possible to estimate the evolution of the quality of the water across the lake.

This model is used to obtain indicators that quantify the environmental criteria selected in the multicriteria analysis for the different scenarious: the degree of light in the water; and the concentration of clorophile-a.

The agro-environmental model of the basin is based on a linear programming model applied to the azorean dairy farms (Silva, 2001):

- Agricultural activities for low lands were not considered because all the basin is located on medium and high altitudes;
- Land uses were differentiated by type (wild forest, production forest, high pastures, medium pastures, forages and agriculture), by intensity of pastures, forages and agriculture (intensive or extensive), by sub-basin (Cemitério stream and others) and by area (commons, public area, highlands, Cemitério, Romangos, Arrebentões, Cerrado das Freiras, Margens da Lagoa, Bacias Endorreicas and agricultural area around the village);
- Two environmental restrictions were included (soil erosion and emission of phosphorus) for each sub-basin. The technical coefficients for these restrictions were retrieved from an hydrological model (OPUS) (http://www3.bae.ncsu.edu/Regional-Bulletins/Modeling-Bulletin/Opus_sbull.html) calibrated by José Fontes (2000) for the Azores pastures and forages.
- Feed supplement was discriminated by bimestrial and nutritional equilibrium equations were introduced to substitute imposed restrictions on cattle per hectare.
- Furthermore the correction of technical coefficients for lower use of fertilizer were estimated based on the results obtained by João Reis (2002).

The variables of the agro-environmental model are:

- $X1_{ij}$ – High pasture area by zone (i) and intensity (j), for all i and j.
- $X2_{ij}$ – Medium pasture area by zone (i) and intensity (j), for all i and j.
- $X3_{ij}$ – Forage area by zone (i) and intensity (j), for all i and j.
- $X4_{i}$ – Forest area by zone (i), for all i.
- $X5_{i}$ – Wild forest by zone (i), for all i.
- $X6_{k}$ – Feed by bimestrial (k), for all k.
- X7 – Cows per year
- X8 – Milk per year
- X9 – Other cattle sold per year (in number)
- $X10_{k}$ – working hours by bimestrial (k), for all k.
- $X11_{m}$ – Phosphorus emissions by sub basin (m)
- $X12_{m}$ – Erosion by sub basin (m).

The coefficients of the Objective Function are positive for products (forest, milk and beef) and negative for intermediary products (pastures, forages, feed and labour). All direct subsidies related to the amount produced were included in the coefficients of the Objective Functions.

The following restrictions were taken into account:

- *Land restrictions:* land uses for high and medium areas must be lesser than the areas available for those altitudes.
- *Rotation restrictions:* for pastures and forages wheat cannot occupied more tan 20% of the area at medium altitude. And there is no wheat at high altitude.
- *Labour restrictions:* labour is contracted by bimestrial according to the need for the management of pastures, forages, forests and cattle.
- *Nutritional restrictions*: dairy cattle with 650 Kg and producing 25 litres of milk per day for 305 days of the year. They need 20% of substitution animals the nutrition components considered by bimestrial were Milk Forage Unities, Digestive Protein, Nitrogen Limits, Calcium and Phosphorus. We also took into account restrictions on feed consumption and the equilibrium between Digestive Protein, Nitrogen Limits and Milk Forages Units.
- *Environmental restrictions*: these restrictions related each one of the land uses with erosion and phosphorus emissions according to the type of soil that is occupied. The emissions of phosphorus and the erosion were obtained through the simulation of OPUS model, developed by the Agricultural Research Service of the Department of Agriculture of The United States.

The agro-environmental model was calibrated for the Sete Cidades through a small variation in the nutritional needs in order to get the total milk production of Sete Cidades. Once calibrated it was possible to simulate the eight basic scenarios of the Plan by changing the Right Hand Side of the restriction for phosphorus emissions.

The agro-environmental model generates different land uses. Based on land use we derived an indicator of biodiversity which was used in the multicriteria analysis.

This model is used to obtain indicators to quantify the agro-environmental criteria selected in the multicriteria analysis: Milk production per year; Net value for the economic compensation of the preventive measures; Net value of the social compensation of the preventive measures (employment compensation); Biodiversity; Phosphorus emissions; and Soil erosion.

Objective Function signals	-	-	-	-	-	-	-	+	+	-	0	0
Variables	$X1_{ij}$	$X2_{ij}$	$X3_{ij}$	$X4_{i}$	$X5_{i}$	$X6_{k}$	X7	X8	X9	$X10_{k}$	$X11_{m}$	$X12_{m}$
	High Pastures	Medium Pastures	Forages	Forest	Wild Forest	Feed	Cows	Milk	Other Cattle	Labour	Emissions	Erosion
Land Restrictions												
Rotation Restrictions												
Labour Restrictions												
Nutritional Restrictions												
Environmental Restrictions												

Figure 4. Representation of the Agro-Environmental Model

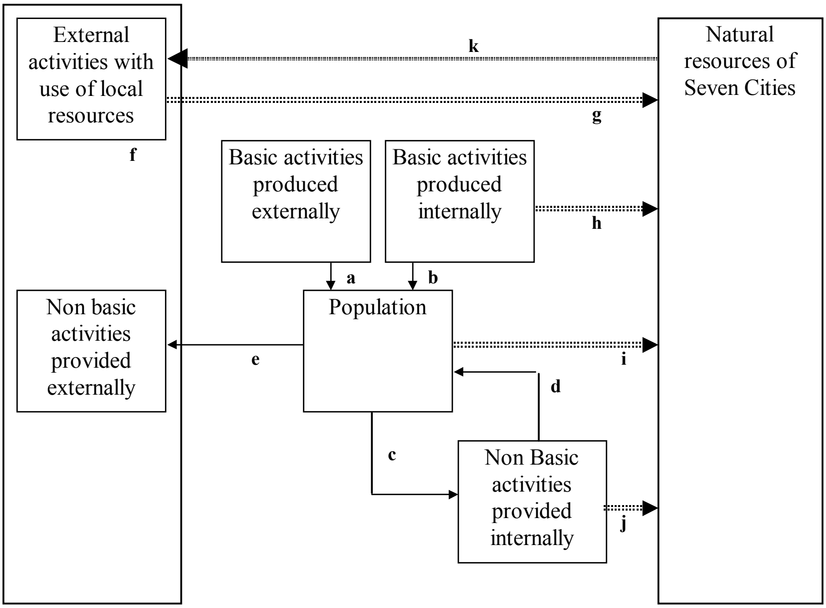

Figure 5. Economic System of Sete Cidades

The model for the local economy is represented in Figure 5. The idea is that the economic system of the village explained by a Base Model (Costa, J.S. et al., 2002), relates to the natural resources of the basin through the arrows: g,h,i,j,k.

Furthermore the coefficients a,b,c,d,e can be integrated in a model to estimate the multiplier effects of changes in the basic activities of the village (dairy production,…) in the total employment and total population of the village (Table 2).

This model is used to obtain indicators to quantify the economic criteria selected in the multicriteria analysis: Number of vehicles that reach the village based on the change in the tourist attraction of the basin; change in the built area which is related to the number of extra jobs created in the tourist sector to compensate the loss in the agricultural sector; number of persons per house which is estimated according to the number of jobs generated by each scenario and the number of houses available; number of students that must go to a school outside the village which is a result of the social compensatory measures and the change in the population; number of second houses which derives from the changes in the economic tissue of the village; and number of actives with an employment in the village.

The method proposed to evaluate and compare the alternative scenarios for the Sete Cidades basin is the Multicriteria Decision Support System.

TABLE 2. Multiplier Effects on the Employment and Population

Employment multiplier	1.75
Population multiplier	5.84

The criteria and their hierarchy presented in Figure 6 was established through a dialogue with the main stakeholders (regional, local and communal entities, farmers' association and NGOs).

To operate these criteria it is necessary to choose an impact descriptor for each one of them. The descriptor can be direct or constructed, quantitative or qualitative, continuous or discrete. Once we have a descriptor associated to each criteria j (j = 1, …, n), it is possible to identify a profile of impacts (g1(a), …, gj(a), …, gn(a)) for each alternative scenario.

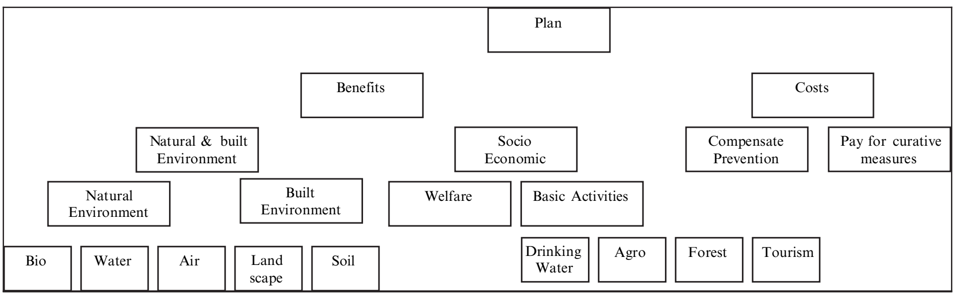

Figure 6. Hierarchy of Evaluation Criteria

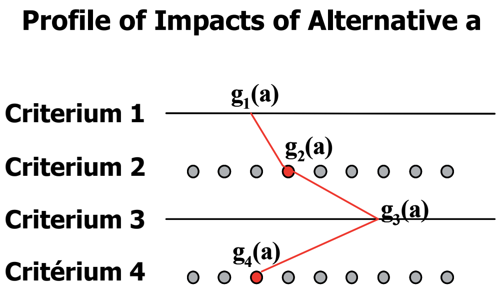

Figure 7. Impacts of Alternative a

Figure 7 illustrates the profile of impact for scenario **a** in a hypothetical situation involving four criteria. The descriptors for criteria 1 and 3 have a continuous scale whereas the descriptors for criteria 2 and 4 have discrete scale.

After that it is possible to define the weights of each criteria based on "*Trade off procedure*", to undertake the global evaluation of the various scenarios and to proceed to the sensitivity analysis.

4. Results

With the three models we get a table of 14 impacts descriptors for each one of the 29 alternative scenarios. With the multicriteria analysis we obtain a selection of the dominant scenarios (Figure 8).

The scenario chosen accounts for 600 cows that produce 3.0 million litres of milk and provide direct employment to 53 farmers and induced employment to more 40 actives. Furthermore the deviation of one of the main water streams

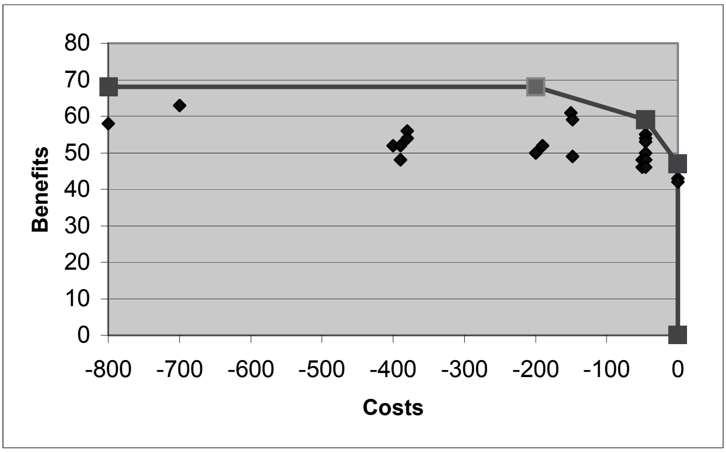

Figure 8. Dominant Scenarios

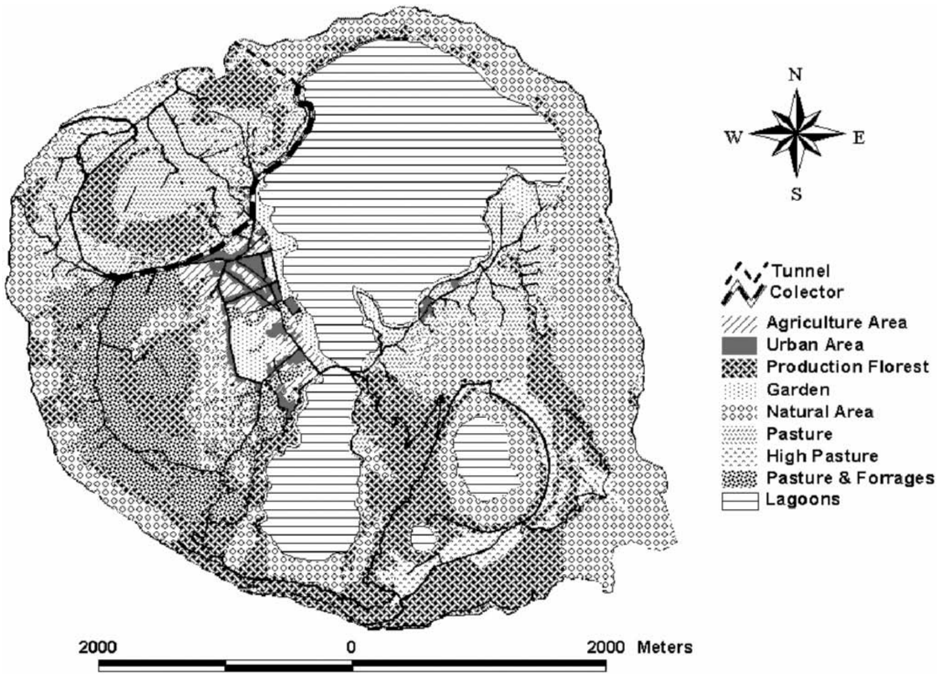

Figure 9. Land Use Plan

that feeds the lagoon will allow a reduction of 63% of the phosphorus load on the lagoon. Compensatory measures, economic and social, will compensate the farmers for their losses and the community for the lost basic employment. The land use plan associated with the chosen scenario is presented in Figure 9.

5. Conclusion and Future Developments

The issue of the eutrophycation of the Sete Cidades Lake in São Miguel show that it is not possible to promote integrated water management without considering the process of land users' decision makers. Mostly because most of the rural community depend on the land use and the generation of the purest water will lead to the end of that community.

Furthermore there is a need to improve the quality of the links between the various models. Actually, the global model was not designed a priori but resulted from the integration of three already developed models. The connections between the economic model of the village and the agro-environmental model had to assume some type of transformation between working hours and employment. On the other hand the link between the agro-environmental model and the environmental model of the lake had to assume some transformation between the emissions from the land into inputs into the lake. Finally the results of the multicriteria analysis could be compared with the outcome from a pure cost-benefit analysis.

Acknowledgements

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ESTABLISHMENT OF THE ISKAR RESERVOIR MINIMUM SANITARY STORAGE CAPACITY

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Abstract. Bulgaria has suffered from considerable economic damages in the past and today, because of frequent droughts and floods. Throughout 1982-1994 one of the drought periods was observed. The runoff diminished and this led to dangerous decline of water levels in reservoirs, and was a major reason for a limited supply of drinking water. Particularly dangerous for drinking water quality were the cases of reaching the water minimum in the reservoirs. This phenomenon was also due to some faults in water management related to water allocation. In many drinking water treatment plants appropriate anti-turbidity and oxidation reagents, reagents for manganese, iron and phytoplankton removal were not used, because of inadequate water treatment technologies applied. A case study for establishing the Iskar Reservoir Minimum Sanitary Storage Capacity (MSSC) according to the water treatment technologies was carried out. The specific chemical and biological water quality state indicators coherent to the water supply function were specified and investigated during one-year period, and the obtained results are given and discussed. In conclusion recommendations that could improve drinking water supply management are made and an attempt for environmental indicators classification for the Iskar Reservoir is made, which could assist policy- and decision-makers in taking useful advanced actions.

Keywords: Iskar Reservoir, water quality, sanitary storage capacity, environmental indicators

1. Introduction

Water reservoirs play an important role in human life, environment and economy. Frequently, they are affected by a variety of natural and anthropogenic factors simultaneously that lead to serious crises.

P. Meire et al. (eds.), Integrated Water Management: Practical Experiences and Case Studies, 155–169.

Such is the case described here, where the Iskar Reservoir, the main source for drinking and industrial water supply of the Sofia City, the capital of Bulgaria, was affected throughout the period 1982-1994. Then the Iskar Reservoir water system was gravity stressed. First, Bulgaria was in a typical cyclic drought period reinforced by the global climate change and second, the water allocation policy for different users of the reservoir was incorrect. Most likely this happened because of the tremendous change in the economic system in Bulgaria, in which a transition from centrally planned to market oriented economy took place. The reservoir was also impacted to some extent by nutrients pollution from point and non-point sources situated in the area. More detailed investigations of the Iskar Reservoir watershed carried out in this period have shown that there were a number of impacts not only on water resources but also on the natural eco-systems, and on the managed ecosystem in the region (forests, crops, etc…). Because of the very low water level some habitual concentration of the water components in the reservoir was modified and some typical for the water system chemical and biological processes were changed. However, from all occurring problems, the sanitary and health problems gained priority, because this water shortage lead to interrupting the water supply of the Sofia City (the so called "water regime", i.e. rationing). Some water quality parameters like manganese, iron, color, taste and smell, as well as phytoplankton, did not meet the standard and by-products like trihalomethanes in the water supply network were recorded due to supplied over chlorinated drinking water. There was also unofficial information on other contaminants, for instance, residual aluminum in the purified water. Problems in the main Sofia City potable water treatment plant (WTP) Pancharevo were provoked and the water treatment costs increased in value. Many technical problems originated from the interrupted water supply and the water supply set cushion. The people did not realize the real situation because there was lack of information and instructions, e.g. for using bottled mineral water, and some of them went on strike.

The situation arisen put the question about more detailed analysis of the problems and the establishment of the MSSC for the Iskar Reservoir according to the drinking water treatment technologies applied at the moment and their possible modification.

1.1. REGULATORY FRAMEWORK FOR WATER QUALITY ASSESSMENT

In the period 1994-1995 of water rationing (called "water regime") the water quality was ruled by Regulation No 7/1986 for flowing surface waters edited by the Committee on Regional Construction and Spatial Planning and by the Bulgarian State Standard (BDS) "Drinking Water" 2823-83.

Table 1 shows the values of parameters used in determining the categories of surface waters, which are of interest for this study. Category I refer to water suitable for drinking water. The categories II and III are generally acceptable from an ecological point of view, but are not of sufficient quality for potable water. The II category is advisable for industry and the III is for irrigation.

BDS "Drinking water" addressed 39 specific water quality parameters. Table 2 shows the values of parameters that are of interest for this study.

TABLE 1. Water quality parameters for the categories of surface water by Regulation No 7

Parameters	Water categories		
	I	II	III
Suspended solids, mg/L	30	50	100
Dissolved oxygen, mgO_2/L	6	4	2
COD ($KMnO_4$), mgO/L	10	30	40
BOD_5, mgO_2/L	5	15	25
Ammonium (NH_4^+), mg/L	0.1	2	5
Phosphorous (PO_4^{-3}), mg/L	0.2	1	2
Iron, mg/L	0.5	1.5	5
Manganese, mg/L	0.1	0.3	0.8

TABLE 2. Drinking water quality parameters by the BDS

Parameters	
COD ($KMnO_4$), mgO/L	2.6
Ammonium (NH_4^+), mg/L	0.0
Phosphorous (PO_4^{-3}), mg/L	0.5
Iron, mg/L	0.2
Manganese, mg/L	0.1

1.2. INFRASTRUCTURE AND RELATED PROBLEMS

Institutions and their divisions that had been responsible for water management in 1982-1995 were: Council of Ministries, National Water Council, Ministry of Regional Development and Construction, Ministry of Agriculture, Forests and Agrarian Reform, Committee of Energy, Ministry of Environment and Water, Ministry of Health, Ministry of Finance, Ministry of Industry, Ministry of Transport, Along the Danube River, Committee on Geology and Mineral Resources, Civil Defense, Bulgarian Academy of Sciences.

Under this structure the water management in Bulgaria was characterized as "centralized decentralization" or "concentration and decentralization at a national level". (Knight et al., 2004). This means that the responsibility for different aspects of water management is assigned to numerous central institutions. The management structure and practices in the 1982-1994 droughts reveals some very significant omissions and shortcomings of water resources management, namely:

- Lack of clarity, accuracy and precision in the regulation of the issue of permits for water use.
- Lack of economic mechanisms and market regulators in both the planning and construction of water sector system, as well as in water resources management.
- Permanent administrative intervention in water affairs.
- Use of information that was not sufficiently comprehensive and featured a low degree of reliability.
- Inadequate expertise of the decision-makers and absence of feedback available to them.
- Absence of modern devices for monitoring incoming and outgoing reservoir water.
- Absence of water meters and absence of a system for monitoring and controlling water consumption.
- Failure to apply modern and scientifically based methods for forecasting runoff, assessing real water demands and optimizing water extraction from the dams.

2. Case Study Description and the Decisional Problem

2.1. THE ISKAR RESERVOIR BACKGROUND

General characteristics. The Iskar Reservoir is one of the biggest reservoirs in Bulgaria with its storage. Situated near Sofia, the capital of Bulgaria, it is the main source for drinking water supply, including household and industrial water supply in the region. The reservoir is of major significance for human health, environment and economy. The Iskar Hydropower System is of great economic benefit.

History. The Iskar Reservoir was built in 1950-1955 in the upper part of the river basin of the longest river in Bulgaria – the Iskar River, belonging to the Danube River Basin. The total watershed of the river is 8 650 km^2 and its length is 368 km. The average river altitude is 1 314 m and the average annual precipitation in the watershed is 758 mm. The watershed of the Iskar Reservoir is 1046 km^2 – 12.4% of the total watershed area. The reservoir has been operated since 1956. The supply of water for the city of Sofia started in 1962.

Economic significance. The Iskar Reservoir fits very well in the surrounding landscape and is used for: power generation, drinking water supply, irrigation, fish farming and recreation, etc. The landscape provides food, drinking water, and moderate climate, and forms a biotope. The Reservoir is part of the big Iskar Hydropower System. The system is operated since 1900, when the first hydroelectric power station in Bulgaria was built with the cooperation of the French - Belgian Society. The system includes other hydropower plants, dams, irrigation systems, etc.

Table 3 refers to some main and specific characteristics of the Iskar Reservoir for the period of 40 years of operation (from 1954 to 1994).

TABLE 3. Characteristics of the Iskar Reservoir

Maximum storage capacity	673 million m^3
Useful storage capacity	580 million m^3
Designed sanitary storage capacity (minimum)	200 million m^3
Dead storage capacity - (warrantable minimum)	93 million m^3
Minimum storage values observed: 1962/1963 1985 January 1986 November 1992 February 1995 February – April 1995	 223 million m^3 206 million m^3 198 million m^3 300 million m^3 57,8 million m^3 53 million m^3
Maximum water surface elevation	816 m

2.2. FORMULATION OF THE PROBLEM

Throughout the 1982-1994 drought, a 31% fall in the runoff was registered compared to the data for the 1890-1994 periods. This fall in the runoff led to the dangerous decline of water level in reservoirs all over the country and was a major reason for a limited supply of drinking water, as already mentioned above. Particularly aggravating for drinking water quality was the reaching of water minimum in the reservoirs. From January 1994 to April 1995 the real water storage in the Iskar Reservoir reached 53 million/m^3 - 7.6% of the total storage. The maximum quantity of phytoplankton in the reservoir reached values up to 6 349 cell/ml. The quality of inflow raw water in the main drinking WTP Pancharevo had the following average parameter values: plankton – 2 654 cells/L, manganese – up to 0.72 mg/L, iron – up to 0.80 mg/L, COD_{KMNO4} – up to 2.89 mg/L. There was no official information on other chemical parameters, because they had not been determined (estimated) in that time.

The main purpose of this study was the establishment of the Iskar Reservoir MSSC and the task was generated by the existing crisis in water supply and sanitary and health risk for the people ensuing from it. (ECO AQUA TECH Project, 1996) The term MSSC, i.e. Sanitary Volume (SV) or Minimum Sanitary Volume (MSV), was not specified for water supply purposes neither in literature nor in the country standards until the mentioned crisis. Sometimes it has been used in practice and specified in the projects of the reservoirs in the context of water storage. The MSV of the Iskar Reservoir could be formulated for the case considered, as a minimum of water volume (storage) in the Iskar Reservoir, under which its water quality meets specific sanitary requirements when water is used for drinking water supply. The MSV of the reservoirs should be determined for each specific case and depending on whether the water is consumed without or after treatment. If the water is not treated, the MSV has to be established only according to BDS "Drinking water". Otherwise, the MSV has to be established according to BDS and the water treatment technology used. Therefore, in the first case the MSV is the minimum volume, under which the water quality meets completely BDS only after disinfection. In the second case, MSV depends on the fact whether the water treatment plant could purify the water to the standard quality limitations. The depth of water intake has to be taken into account when the MSV is established. The term "minimum sanitary volume" does not correspond to permissible minimum volume, recommended and often used in practice. The latter is always equal or bigger but never lowers than MSV. The minimum water storage should be also established after respective investigations of the environment. Such types of investigations have never been carried out in the country and they are not the objective of this study.

Especially for the Iskar Reservoir three values of the MSV could be determined, since the available water treatment technologies enable the raw natural water to be treated in three ways, i.e. in three flows with different water quality:

- Flow A – the technology includes only disinfection with chlorine;
- Flow B – the technology is two-staged (precipitators and filters) and includes preliminary chlorinating, coagulation, flocculation and post-chlorinating (provided at the Pancharevo WTP);
- Flow C – the technology is one-staged (filters) and includes preliminary chlorinating, coagulation, flocculation and post-chlorination. (Provided at the Bistritza WTP, being under construction during this study and put into operation soon after the end of it).

The differences in these technologies normally give the possibility of ensuring sufficient quantities of good quality potable water for the people in the Sofia City, regardless of the raw water quality and within due cost limits. However, if the concentration of manganese is higher when the lower water conditions are reached, the technologies of the Pancharevo and Bistritza WTPs should be modified. The treatment technology of the Bistritza WTP should be also modified when higher values are registered for the turbidity and plankton parameters.

In the Figure 1 a general conception of the decision problem described above with special emphasis (thick lines) on the case when water is extracted only for water supply is given.

Options 1 and 2 (water treatment, variant 1 and 2 – WTV-1 and WTV-2) were used for drinking water supply management in 1994-1995. Later, option 3 (WTV-3) was also used.

However, for an effective long-term period this problem should be considered on the base of a study carried out all over the Iskar Reservoir water system. The problem described and the recommendable decisions should be in conformity, in the first place, with the Iskar Reservoir water allocation for different water functions (users). (IWP BAS Project, 2004) Then at fixed water storage and forecast for the inflow and water use, it will be possible to answer the questions when and what water volume could be allocated to the different users and how the policy- and decision- makers could take adequate decisions.

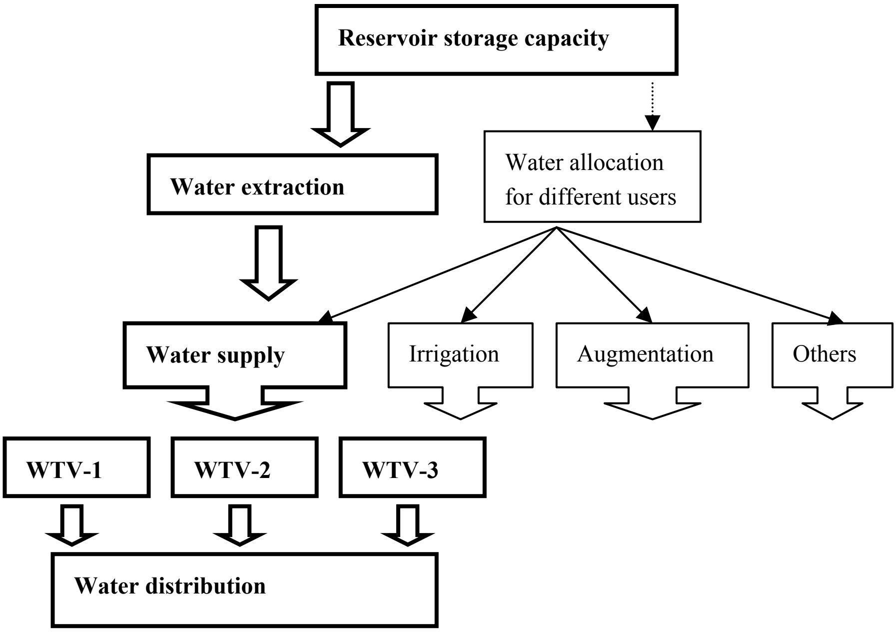

Figure 1. General description of the problem

When the drinking water supply is the first priority, the alternatives of water treatment technologies and processes should be considered too on a case-by-case basis, taking into account the reservoir storage capacity, water allocation, water quality characteristics, existing treatment, nature of distribution system and the necessity of ensuring public health protection. This integral approach is not applied yet at the upper levels of water resources management in Bulgaria. Recently, a methodology for water allocation of the reservoirs was developed but only quantitative aspects of the water resource are taken into consideration.

The aspect related to the costs has to be considered too. It is connected mainly with the determination of the cost/effect function for the different water treatment technologies and the water price eventually. However, an overall assessment of all types of water treatment options is necessary and it includes, as a rule, a cost benefit analysis (CBA) and/or its special case – a cost effectiveness analysis (CEA). Such type of analysis is carried out only for several projects of wastewater treatment plants in the country. There are no legislative requirements and guidelines for conducting such economic analyses in Bulgaria for the present.

Table 4 shows an widely used in practice model the could be applied for an overall assessment summarized on the basis of some types of benefits and costs for the above-described three variants of water treatment technologies. It is not

TABLE 4. A model of overall assessment of water treatment alternatives

<table>
<tr><th></th><th></th><th>Microbiological safety</th><th>Chemical safety</th><th>Customer aesthetics</th><th>Easy for monitoring</th><th>Ability to treat difficult waters</th><th>Capital costs</th><th>Operating costs</th><th>State of commercial development</th><th>Scale up</th><th>Waste production and energy use</th><th>Reliability</th></tr>
<tr><td rowspan="3">Water from the reservoir</td><td>WTV-1
Chlorination</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>WTV-2
Precipitators and filters:
preliminary chlorination, coagulation, flocculation and post-chlorination</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>WTV-3
Filters:
Preliminary chlorination, coagulation, flocculation and post-chlorination</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

quite easy to fill in this information and this task could be a subject of another special study.

Several criteria could be used for an overall assessment of the water treatment alternatives - microbiological and chemical safety, cost, reliability etc., and they could show if the alternatives can have benefits such as improved chemical safety and customer aesthetics, but also disadvantages such as difficulty in monitoring process performance, etc. In the matrix given in Table IV, the alternatives could be graded according to the respective criteria, such as: better than average (+), worse than average (–), average (•). The treatment technologies and processes could be estimated together and/or separately.

The used water treatment technologies and processes should be also evaluated with regard to the relative risks associated and the ways, in which output quality could deviate from the accepted target values that have to be identified and ranked.

3. Methods and Results

A program for water quality and water level direct observation and for the result interpretation was developed. The place and depth of 4 typical profiles and 4 sampling points were specified. The samples were taken at 0.5, 10, 20, 30, 40 m from the surface and at 1.5 to 2 m above the bottom. The sampling program included one year period for sampling and determination of selected organoleptic, physical, chemical, biological and microbiological parameters: color, taste and smell, turbidity and transparency, temperature, dissolved oxygen and COD_{KMnO4}, nutrients – ammonium NH_4^+, nitrite NO_2^-, nitrate NO_3^- and phosphates PO_4^{-3}, manganese and iron, hardness, the microbe number and coli form count. The phytoplankton produced from 24 basic taxons grouped systematically was determined and they are:

- CIANOPHYTA - Mikrocystis aeruginosa Kg., Anabaena spiroides Kleb. CILLARIOPHYTA - Asterionalla farmosa Hass., Synedra Acus Kg., Melosira granulate var. Angustissima O. Mull, Melosira varians Ag., Fragilaria capucina Desm., Navicula sp. Diversa, Nitzschia sp. Diversa, Ciclotella ocellata Pant., Ciclotella kutzingiana Thw., Cimbella sp., Gyrosigma sp.
- PYRROPHYTA - Ceratium hirundinella (OFM) Bergh.
- CHLOROPHYTA – Pediastrum clathrmtum Lemm., Staurastrum planctonicum (Teiling), Scenedesmus qradicanta West., Scenedesmus bijugatus Kutz., Sphaerocystis sp., Oocyctis sp., Kirchneriella obesa (West) Schmiddle, Closterium aciculare (Tuffen) W. West., Botryococcus Braunii Kutz

The EN and ISO Standards, BDS EN, BDS ISO and BDS were used for analyzing the gathered samples.

The sampling days were singled out according to the weather conditions. A complete analysis of water samples was carried out twice. The deposits were not analyzed, only the filling of water cup was registered. For evaluating the situation and for determining the MSV under the constraints of the priority function – drinking water supply, the selection of water quality parameters was made mainly on the expert's experience and on own previous information, because of lack of systematic water quality information. The collected information was analyzed and interpreted for water storage, for each of the water quality parameters and for combined parameters, where necessary. At the beginning of the case study, September 1995, the water volume was already 264 millions m^3. The Iskar Reservoir sampling point's scheme is given in Figure 2.

The obtained results for the parameters are discussed in brief below, as follows:

Microbiological The values are habitual for the reservoir, which is typically mezotrophic. The microbe number is up to 200 stocks/ml and the coli form counts are from 10 to more than 100 ml. In this case this indicator is not determinative because the technologies include chlorination.

Biological The phytoplankton amount is in the range of the cyclic variation normally observed along the years. During the spring and autumn homothermous its amount is uniformly distributed in depth. This sometimes causes considerable difficulties in WTPs. (For instance in March 1982 and in December 1983, when *Closterium aciculare* was growing and the total biomass was 9.4 g/m^3). As a rule the maximum amount is in the surface layers to a depth of 5 m. During this study the phytoplankton was moderately cultivated and had a maximum only in July 1996. This maximum resulted from *Fragilaria crotonensis* and was 5.93 gr/m^3 (6 412 000 cells/l). In this case this indicator is not determinative because the technologies include chlorination.

Color Vastly fluctuates. In September – October 1995 and May 1996 reached to 40°Pt as a result of the intensive growth of phytoplankton species but usually was about 10°Pt. The rivers running into the lake often intensify the color.

Taste and smell Normally the water has a good taste and is without smell. Occasionally algae smell is found.

Turbidity Practically it is about 1.5 TU during all the years. Only in September, as a result of "autumn bloom", the value of 3.5 TU was reached in the surface layer to 10 m.

Transparency Normally by the method Sekki it is 3.5 – 4.0 m. In September, as a result of "autumn bloom", it was 1.5 m.

Temperature During the winter months the temperature of the water intake horizon is 3 – 4°C and in July – August it reaches 12 – 13°C.

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Dissolved oxygen As is well-known the dissolved oxygen amount depends mainly on temperature, aeration of water layers, the fresh waters of snow or rain flowing into the lake and the growth of plankton and other species that consume oxygen. In the greater part of the year the dissolved oxygen content is lower than the relevant equilibrium. In May and June the upper layers (to 5 - 6 m) were saturated and the surplus was nearly 10%. From June to September the consuming of oxygen grew up and the maximum to the bottom layers reached 92%. In November and December the typical autumn homothermous occurred that could be seen from the values of temperature, oxygen amount, etc.

As a result of the oxygen deficit near the bottom layers, an aerobic mineralization of the organic matter in the sediments occurred. Bivalent soluble manganese and iron and hydrogen sulphuric compounds were produced.

COD_{KMnO4} In winter months it was 2.5 mgO/L and in spring and summer – 3.5 mgO/L. The highest values were near the bottom. The COD_{KMNO4} of the five tributaries varies from 3.0 mg/L to 7.1 mg/L (maximum value was reached in May 1996).

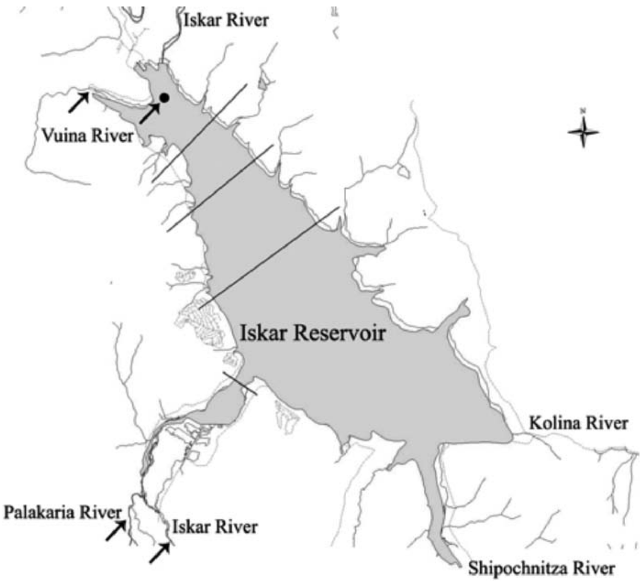

Figure 2. The Iskar Reservoir sampling points scheme

Nutrients:

- **Ammonium [NH_4^+]** - in the surface layers it was detected to a depth of 10 m (up to 0.3 mg/L in September 1995) and in the rest times it was below 0.1 mg/L. The five small rivers were the sources of ammonium and the highest concentration was measured in the main one – the Iskar River (from 0.3 to 2.2 mg/L in December 1995)
- **Nitrites [NO^-_2]** - normally during the year the concentrations were from 0.01 to 0.02 mg/L but in the tributaries they were a little bit higher
- **Nitrates [NO^-_3]** - the content of nitrates during the year as a rule is very low and varies from 3 to 4 mg/L, the content in the tributaries being from 10 – 12 mg/L
- **Phosphates [PO_4^{-3}]** $^-$ in spring and summer they were 0.1 - 03 mg/L. In autumn and winter they were 0.3 – 0.4 mg/L. Nevertheless, special measures should be taken for decreasing phosphate content (0.7 mg/L average) in the Iskar River taking into account the treatment costs.

Manganese ***Total*** In the period the highest measured concentration was 0.32 mg/L at a depth of 50 m (July 1996). To the 25th m there was no manganese at this time. In December 1995 as a result of intensive homothermia, the manganese was 0.15 mg/L along the whole depth of the lake. The concentrations during September 1995 – September 1996 were lower because the water volume was higher.

Iron ***Total*** The iron content was from 0.1 to 0.2 mg/L during the studied period. In the tributaries it was 0.5 – 0.6 mg/L and was detected in the suspended solids mainly. In this area the higher iron concentration is an indicator for industrial pollution.

Hardness The values vary in the range from 3 – 4 ^{o}D.

4. Conclusions

The Iskar Reservoir water quality practically meets the standard requirements concerning drinking water quality treatment technologies all the year round, except when the water level is very low. Then the parameters like plankton, turbidity, color, COD_{KMnO4} and manganese do not meet the standard. The most unfavorable are the periods April – May and September – October when the phytoplankton has maximum growth.

For the particular case study the following recommendable MSSCs (MSV) are established depending on the existing water treatment technologies:

- Without water treatment – 325 million m^3;
- Treatment in Pancharevo WTP – 100 million m^3;
- Treatment in Bistritza WTP – 130 million m^3

The option that the decision makers have to choose depends mainly on water consumption.

For human health safety and for environmental protection it is recommendable that the MSSC should be in the range 150 – 200 millions m^3 although the treatment plants have vastly bigger technological potentialities.

The wastewater treatment plant of the town of Samokov situated at the upper part of the Iskar River should be operated more efficiently for decreasing the nutrient load.

The treatment technologies of the Pancharevo and Bistritza water treatment plants needs modification so that manganese is removed. The pre-treatment with $KMnO_4$ is advisable.

It is necessary to carry out systematic sampling and analyses of the selected water quantity and quality indicators/parameters in order to indicate the state of the water system. For this purpose the monitoring program should be designed.

Operational and strategic management plans for the Iskar Reservoir water use and protection should be developed. Within these plans the corresponding CBA and/or CEA have to be performed before making effective decisions.

In general, all of the above described problems and issues are a precedent showing that a serious crisis in the water supply and environment could be caused not only by current natural and human controllable and non-controllable phenomena, but also by water resource mismanagement. The following Table 6 represents the "pressure, state and response" environmental indicators identified on the basis of the results obtained through direct observation, their interpretation and the conclusions drawn for establishing the MSSCs of the Iskar Reservoir.

TABLE 5. The pressure, state and response indicators

Issue/Problem	**Pressure indicators** Measure the forces on the retained water storage caused by natural processes and human activities	**State indicators** Measure the quality and the stock of water resource/storage Monitor this indicators and established trends	**Response indicators** Illustrate action and activities intended to address the current state of water or the pressure acting upon it from the society
1	2	3	4
Environmental health/Environmental risk			
Resource: Water	Use of natural resource: Water extraction Water allocation Number of planning applications	Indicators: Quantity of water storage Sub-ndicators/parameters:	Management strategy for water resources usage at a sub-basin level

(OECD, 2001, 2003) The policy relevance and utility for users, analytical soundness and measurability are used as criteria for selection. It is known that correctly selected environmental/water and human health indicators describe the shortcomings in water management. This is an opportunity of applying adequate response indicators. In this sense the selected indicators presented here need additional discussion and specification due to the inadequate integration, for the moment, of water management with health protection.

TABLE 6. The pressure, state and response indicators

1	2	3	4
		- Biological water quality: Phytoplankton community, concentration total biomass - Chemical water quality: Dissolved oxygen, total phosphorous and nitrogen, manganese, by-products	Local operational and strategic plans for management Water balance Regulation of water income to the reservoir Hydrological modeling of the watershed flow Modeling of water quality Decision support system State investment in water management, etc
Drinking water	Water demand Water supplied	Supplied water quantity and its quality Water leakages	Balance of water demand and water supply Water price Information should be explicated and could be open for ordinary people Water problems Perception
Climate change	Long term change of temperature	Air temperature Precipitation River discharge	Climate change analysis of the impacts on water resources, natural and managed ecosystems, and on society, including health and hygienic aspects
Pollution: Euthrofication	Discharge into water courses flowing to the reservoir Processes in the sediment	Total nitrogen and phosphorous emission from point and non-point sources BOD emission Deposits quantity and composition Specific elements enhancing euthrofication	Installation of pollution abatement measures Monitoring program for pollution Regulations

TABLE 7. The pressure, state and response indicators, continuation

1	2	3	4
Human health/Health risk and hygienic aspects			
Resource: Drinking water	Water storage Water and sediment quality Available water treatment technologies Water allocation	Water storage Duration of interrupted water supply (regimes) Toxic elements: Manganese and by-products: trihalomethanes, etc. Sick rate during the regimes	Water balance Water allocation methodology Water demand/water supply balance Water price, etc.

Acknowledgements

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EUTROPHICATION IN THE BLACKWATER RIVER CATCHMENT, IRELAND

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Abstract. The Ulster Blackwater River has a cross-border catchment and is one of the major inflowing rivers of Lough Neagh. It is a traditional salmon fishery that has been impacted by channelisation and eutrophication. There is evidence linking agricultural soils as sources of acute mass phosphorus transfer to the river system during storm events and chronic phosphorus transfers from other sources compound this during non-storm periods. Management of this particular impact is being demonstrated in a project in three 5km^2 sub-catchments of the Blackwater River. The aims are to define and mitigate against both acute and chronic phosphorus transfers and to focus this management within a landscape framework. This work integrates agricultural stakeholders with scientists and a tripartite organization of local jurisdictions.

Keywords: eutrophication; phosphorus; catchments

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1. Introduction

The Blackwater River is encompassed by a 1,480km^2 cross-border catchment that has shared jurisdictions in Northern Ireland and the Republic of Ireland. It is also one of six major inflowing rivers into the regionally and internationally important Lough Neagh (370km^2) (Figure 1). The landscape of the Blackwater River is dominated by topography of glacial origin (drumlins – small ovoid hills of compacted till) that is representative of a large part of the north of Ireland. Soils have developed on dense clay till, isolating Carboniferous series aquifers, and are, for the most part, gleys and humic gleys. Inter-drumlin lakes are also a feature of this landscape type. Landuse in the catchment is typically agricultural with approximately 95% grasslands managed for pastures and silage meadows for dairy, beef and sheep farming.

Annual rainfall is approximately 800 to 1,000mm with up 70% as annual runoff. Drainage schemes during the 1980s were undertaken to improve agricultural land by a process of channelisation (deepening and straightening reaches) followed by arterial drainage similar to many river catchments in Ireland (Essery and Wilcock, 1991). Runoff regimes have been accordingly altered with short but high storm hydrographs and suppressed base flows. As the Blackwater River was a traditional salmonid fishery, restoration of the river included construction of stone weirs to aid aeration, and replacement of scoured areas with artificial spawning gravel. This has had limited success and many tributaries remain devoid of salmonids, especially in the juvenile range.

Typical of the Irish landscape, the rural population density is higher than neighbouring Great Britain and in the Blackwater region this is approximately 0.35 to 0.5 persons/ha (including and excluding small urban centres, respectively) (NISRA, 2001).

The catchment is situated within the Neagh-Bann International River Basin District (IRBD) in Irish Eco-region 17 (Water Framework Directive [WFD] designation).

2. Case Study

An initiative by the three local jurisdictions within the boundary of the Blackwater River watershed which includes Dungannon and South Tyrone Borough Council, Co. Tyrone, Armagh City and District Council, Co. Armagh (both Northern Ireland) and Monaghan County Council, Co. Monaghan (Republic of Ireland) was funded in 1995 under the EU INTERREG II programme to address 'quality of life' issues using the catchment boundary as the management framework.

Following the publication of an independently commissioned management plan (BCRDS, 1997) a framework was produced to assist in promoting management under the umbrella of the Blackwater Regional Partnership. This group has since secured funding for initiatives to improve rural infrastructure, develop tourism, improve access to resources, promote environmental education, and restock river reaches with salmonid ova and fry.

Most major tributaries are routinely monitored for chemical and biological indicators of water quality and this is combined with a comprehensive hydrometric network. In the Northern Ireland portion of the Blackwater River this work falls within the remit of the Environment and Heritage Service. In Co. Monaghan, similar work is undertaken at County Council level.

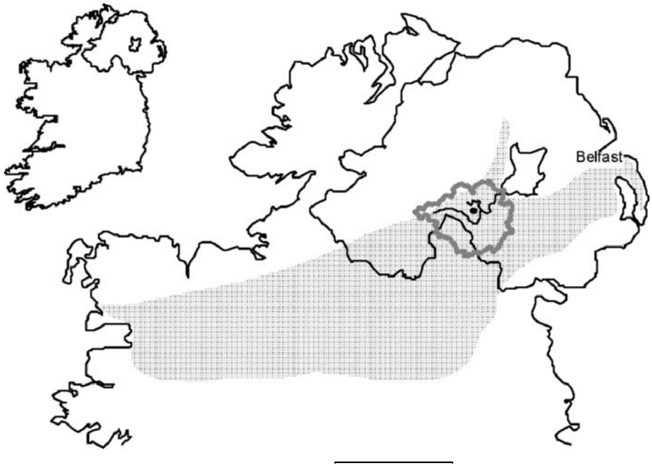

Figure 1. The Irish drumlin belt (shaded) and the Blackwater River catchment

A major tributary of the Blackwater River in Co. Tyrone is the Oona Water ($102km^2$). This sub-catchment is part of the Catchment Hydrology and Sustainable Management (CHASM) project sponsored by the UK government and includes similar sized catchments in Great Britain in a single experimental design. This experiment is designed to study scale issues in hydrology by monitoring all water balance components in a nested catchment plan. In the Oona Water hydrometric stations have been established at the meso-scale ($92km^2$), mini-scale (9, 10 and $23km^2$) and micro-scale (1.5, 1.8 and $2.5km^2$). Meteorology is monitored by automatic weather stations and a rain gauge network (1gauge/$10km^2$). All parameters are measured at a high temporal resolution (5 to 15 minutes). One of the major challenges that the CHASM network is addressing is how to predict large-scale hydrological phenomena from small-scale measurements. A further output is the facilitation of a high-resolution hydrological infrastructure onto which other research can be linked or augmented.

Eutrophication of freshwaters by increasing phosphorus (P) transfers from land is probably one of the most persistent water quality issues in Ireland (Foy et al., 2003; McGarrigle et al., 2001). In a linked research project sponsored by the Republic of Ireland government, the Oona Water CHASM infrastructure was used to provide hydrometeorological data to a project on P transfers from agricultural land. Monitoring at field (0.15km^2), farm (0.62km^2) and landscape (84.5km^2) scales, P transfers were measured using discrete and automated sampling techniques and biased towards capturing the high P transfers during storm flows. Results during the 2002 calendar year indicated that P transfers from the field and farm scale streams were high at 2.4kgTP/ha/yr and mostly transferred during acute storm events. At the landscape scale, however, high background P concentrations between storms chronically enriched the river and this increased

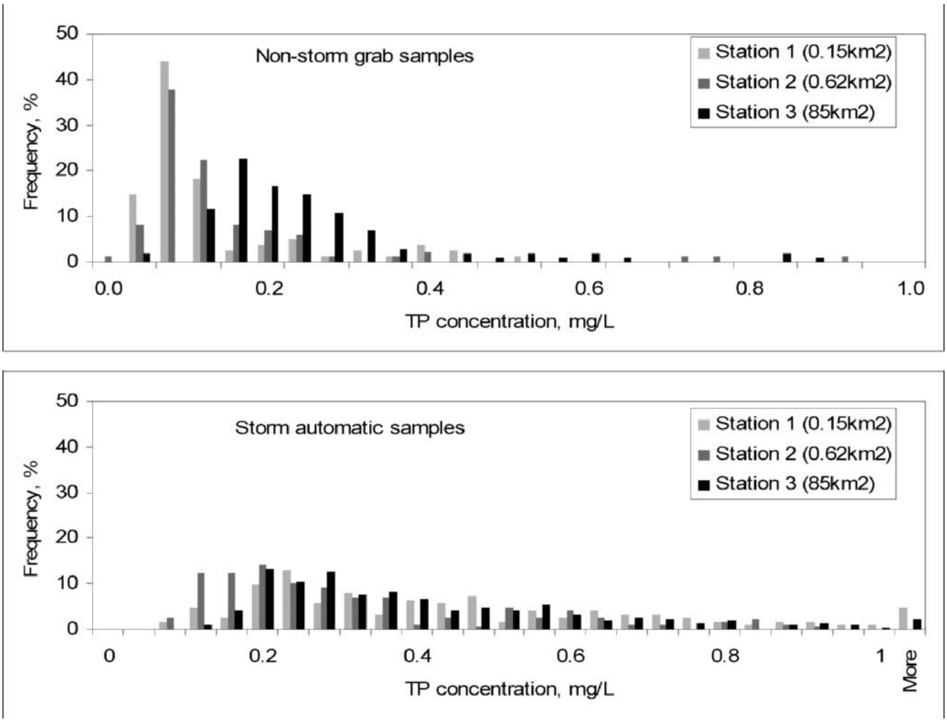

Figure 2. Distribution of non-storm and storm TP samples at three sites on the Oona Water river during the 2002 calendar. A greater frequency of high P concentrations during low flows at the 84.5km^2 landscape scale site produced a further 0.6kgTP/ha/yr than field/farm scale sites

the annual load to 3.1 kg/ha/yr (Figure 2) (Jordan et al., 2005a). At this scale, it was noted that there were only 20% of the total Oona Water catchment population connected to secondary waste water treatment plants and that the remaining population (approximately 2,700) relied on domestic septic tanks for waste water disposal. An inference from these data is that the human population could, in part, be responsible for the chronically high P concentrations observed in the river at the landscape scale between storm events.

3. Methods and Future Developments

It is with this background that a new initiative, Blackwater TRACE (**T**rans-boundary **R**iver-basin **A**ction for **C**ommunity and **E**nvironment), also funded under the INTERREG programme, was started in 2004 to address water quality issues in the Blackwater River catchment. Realising that nutrient transfer is from multiple sources and its transfer rate (mostly high flow) and subsequent river impact (mostly low flow) is linked to hydrological regimes, three 5km^2 sub-catchments in each of the managing jurisdictions have been delineated and equipped with water quantity and quality monitoring equipment. This size was chosen to encompass both agricultural and domestic sources of nutrients (but omitting waste water treatment works). One particular problem of prioritizing

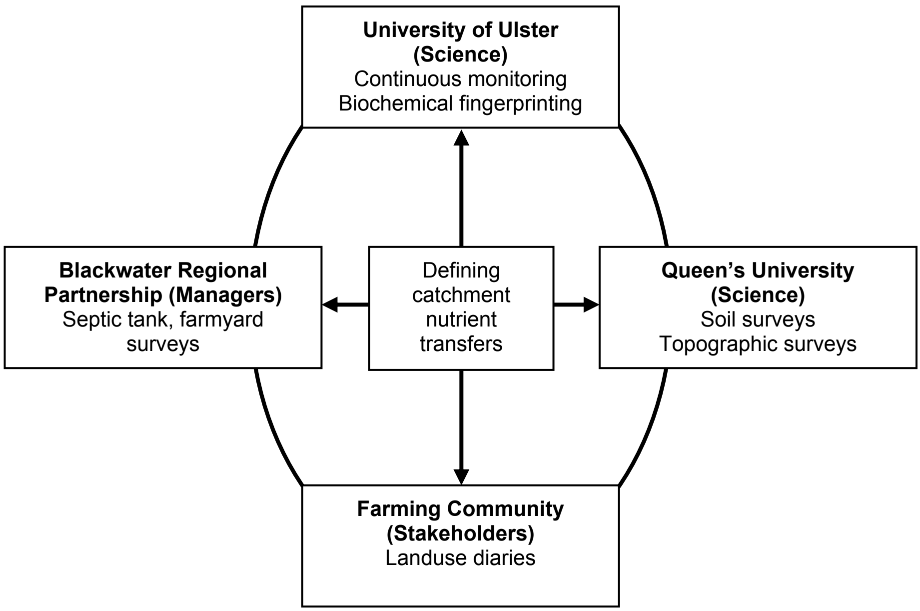

Figure 3. An integrated approach to defining phosphorus transfers at the catchment scale in the Blackwater TRACE project

management efforts is defining where the sources of nutrients are originating from and a part of the project will use biochemical-fingerprinting techniques to demonstrate to stakeholders the magnitude of certain slurry/sewage sources (Nash and Halliwell, 2000). This is being promoted not as blame apportionment but rather as ownership of the water quality problem at the catchment scale. The definition phase will also include comprehensive soil nutrient testing, septic tank, farmyard infrastructure and riparian area surveys and recording the major phases of landuse management. The definition of multi-source nutrient transfers therefore links together scientists, managers and stakeholders in an integrated framework (Figure 3).

In 2006 the sources had been defined, and measures planned for mitigation are considered commensurate with the objectives of the WFD. These measures include, for example, promoting nutrient management plans on agricultural soils, promoting yard management to avoid or reduce unnecessary dirty water production and yard runoff, fencing off stream reaches where there is damage to banks or direct contamination from cattle access for drinking, replacing defective septic tanks. There currently exists both a legal and a voluntary framework for undertaking these measures.

As this work is being conducted in focussed sub-catchments, the intention is to demonstrate a stepped change in water quality at both high flow (acute P transfers) and low flow (chronic P transfers). In-situ P analysers are providing a high-resolution dataset that will be augmented by other parameters of water quality, including turbidity, dissolved, pH and conductivity. These high resolution data are providing new insights into nutrient transfers at the catchment scale and delineate transfers into specific storm and non-storm events. This will aid with reviewing the success of mitigation measures across all river discharge ranges (Jordan et al., 2005b). Further project evaluation will take the form of farmer appraisal and also with regard to the ability of cross-border jurisdictions to manage water quality problems from multiple sources. This science-stakeholder-management initiative was recognised by the UNESCO HELP programme and endorsed the Blackwater River – Oona Water system as an Operational Basin.

Acknowledgments

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THE PROPOSAL OF IWRM IN THE BOUREGREG BASIN AND HOW IT FITS WITH THE UNESCO/HELP POLICY PROGRAM

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Abstract. The Bouregreg basin in Morocco, having a surface of around 10000 km^2, has its water resources diminishing over time at an increasing rate because of the rising demand and the climatic conditions. The total population in the basin is around 2 million persons and lives mainly in the urban centres of Rabat, Sale and Khémisset. The main land uses in the basin are agriculture, grazing, forest, urban and rural settlements. The aim of proposing the basin in the UNESCO/HELP programme is to contribute to the integrated management of water resources in this basin by conducting studies on the definition of the development of potentials and constraints of the resource, identification of the changes that have arise in uses and in biological resources, the characterisation of the current state of the ecosystem and assessing modifications in these components, the determination of the current state of human activities and natural phenomena and the incorporation of this knowledge to draw a diagnosis of the site which will serve as a basis for developing a framework for an Integrated master plan for integrated water management in the basin.

Keywords: Bouregreg basin, HELP program, water resources, Morocco

1. Introduction

The Bouregreg basin (Morocco) has a surface area of around 10000 km^2. The altitude varies from sea level to 1627 m, with 50% of the surface area falling within an altitude range of 500 to 1000 m. The Bouregreg River has a fairly low overall slope of around 0.6% and rarely exceeds 1.0% throughout its course. From a geological point of view, the basin is mainly shaped of hills and plateaux of the Central and Coastal Meseta and a marshy alluvial plain with recent deposits of grey silt and sludge. It is therefore subdivided into two

P. Meire et al. (eds.), Integrated Water Management: Practical Experiences and Case Studies, 179–187.

distinct sub-basins: the north eastern part which corresponds to the actual Bouregreg basin (around 3830 km^2 of the surface area) and the south western part, corresponding to the basin of its main tributary (Oued Grou) which itself has two tributaries (Oued Korifla and Oued Akreuch) and a surface area of 5670 km^2.

The mean annual rainfall varies from around 400 mm on the coastal region to 760 mm in the high mountains, with a big seasonal contrast from the dry season (May to September) when it receives 8% of annual rainfall to the rainy season (October to April) when it gets 92% of it.

The basin has not experienced catastrophic events such as floods because of its incision, but it has been affected by the main droughts which struck the whole country during the 1980s and early 1990s.

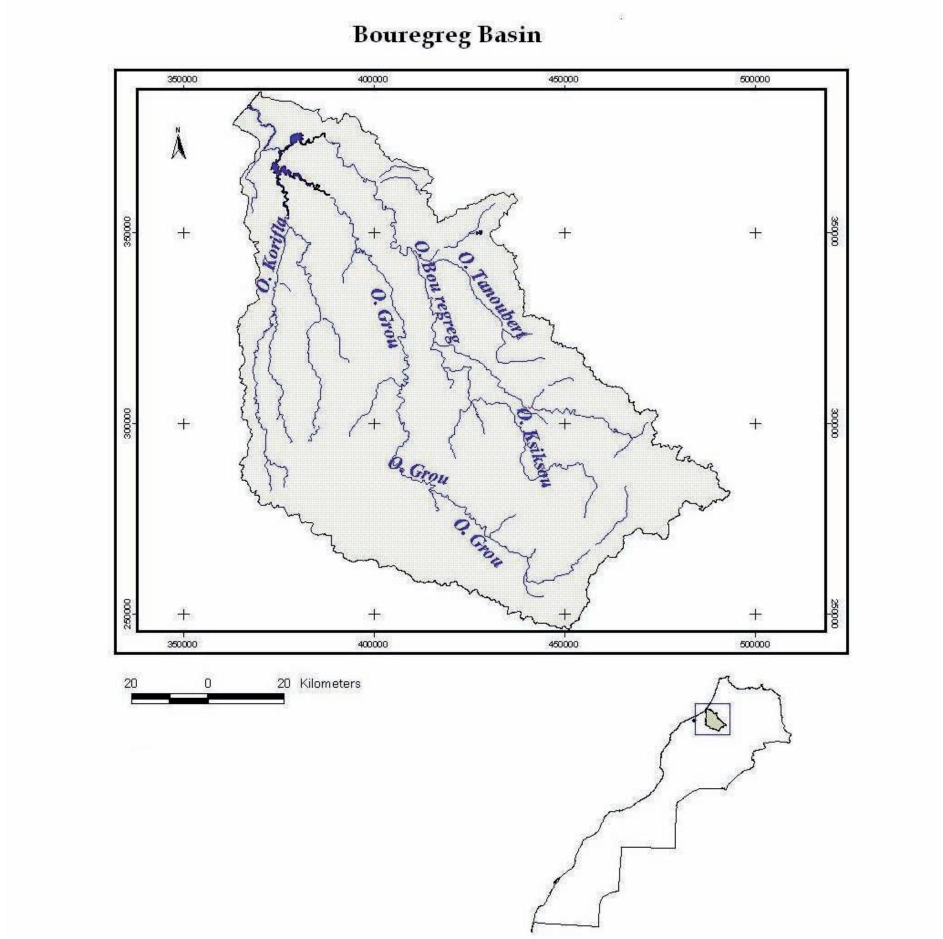

Figure 1. The Bouregreg basin limits and main rivers

2. Water Resources and Uses in the Basin

Water resources in the basin are diminishing over time at an increasing rate because of the rising demand and climatic conditions. Natural resources per capita currently stand at around 700 m^3 per person per year and by 2010, more than 80% of the population will have access to only 200 m^3 per person per year. There are two main groundwater resources available within the basin: Sehoul and Tanoubart, with a low rainwater storage capacity. Rainfall is irregular in time and the impermeability of the surface of the basin leads to substantial losses in the surface water and the quality of this water is threatened by human settlements downstream.

The annual mean of surface water availability is 1080 billion m^3. This water is mobilised by a dam located downstream which has a capacity of around 600 billion m^3. In addition to this dam, projects are in progress to ensure a good water supply, e.g., raising the height of the existing dam to increase its storage capacity and constructing two other small dams.

However, the strong demand for drinking and industrial water paralleled with inadequate local resources means that meeting these needs is heavily dependent on water transfers from other basins. Hydro agricultural and industrial development combined with the large quantities of water abstracted to meet potable water needs have led to the depletion of watercourses resulting in conflicts between competing users. Groundwater aquifers also are threatened by excessive withdrawals.

The demand for potable water and water for industry in 2000 was around 94, and it will reach 142 billion m^3 in the year 2020. Moreover, by this year, the demand of water for agriculture will be of 400 billion m^3 per year even though today it is not really significant.

3. Population, Land Uses and Environmental Threats

The total population in the basin is around 2 million persons and lives mainly in the urban centres of Rabat, Sale and Khémisset. The average density is 217 inhabitants per km^2, and it ranges from 7 inhab/km^2 in remote areas to 10500 in the capital.

The main land uses in the basin are agriculture, grazing, forest, urban and rural settlements. The forest vegetation is composed principally by Quercus suber, plantations of eucalyptus and pines, and dwarf palm tree indicating an advanced degradation process of the natural forest. The lower valley of Bouregreg and the estuary contain significant wetland vegetation and avifauna habitats.

A large part of the basin is exposed to intense erosion. The valley contains a number of quarries which cause several problems for the natural and socio-economic environments. The neighbouring urban centres often discharge their waste water directly into the ocean or the basin. The municipal rubbish dumps for these centres are located in river banks of Bouregreg. The pollution caused by these dumps represents a threat for the human health mostly for the inhabitants of shantytown settlements located in the vicinity of the disposal area. The pottery craft mills which are quite widespread in the surrounding of the low valley of the Bouregreg River are suspected of being a source of very high concentrations of lead in the atmosphere and in plants.

The greatest environmental problem in the basin is water pollution caused mainly by urban discharges and quarrying. Clean water is becoming an increasingly scarce resource because of contamination from domestic waste or from industrial or agricultural effluents. Polluted water endangers human life as well as aquatic life and threatens agricultural production. Reduced soil fertility through erosion or the use of polluted water; the silting up of dams; the total or partial loss of the river's fish farming potential; morbidity related to waterborne diseases, etc., are just some of the catchment's-based issues which are already a reality or are looming on the horizon.

4. Water Policy

Current water legislation reforms and the improvement of rules governing water resources have been combined under a single law on water. Almost ten years ago, a single law related to the management of water resources was put into effect in Morocco. This law (loi n° 10-95) was promulgated in 1995 and came into effect in the year 2000, following a period of transition during which water users were requested to declare their officially-recognised water-user rights, otherwise these rights would no longer be acknowledged and water would become public property. This law was created in order to repeal all previous laws and regulations and has led to two new concepts: user pays and polluter pays principles. It has also established river basin agencies and a national water regulatory body. The Water Council is responsible for the Integrated Water Development Master Plan for different river basins.

An Integrated Water Resources Master Plan has been produced but its application is not yet fully implemented. There is a long way to go before available resources meet expressed needs of implementing texts of the Law 10-95 which have been drafted but have not yet been fully applied. Efficient management of the public hydraulic domain is impeded by illegal occupation as well as by the damage caused by rubble removal from the river banks in the Bouregreg Valley.

The law on water is based on a number of principles derived from several objectives including the finalisation of a development and water resource distribution plan through consultation between users and public authorities;

safeguarding public health by controlling the water exploitation, distribution and sale of water for human consumption: monitoring activities suspected to pollute water resources; the rational distribution of water resources during periods of drought in order to alleviate the effects of water shortage and reasserting the value of agriculture by improving water development and use for agricultural purposes.

Seven basin agencies have been set up throughout the country including one which is in charge of the Bouregreg basin. These agencies together form an adequate framework to achieve interdependent and participatory water management at the river basin level.

5. How do the Basin Issues Fit With the HELP Policy Issues?

Since 1988, Morocco has initiated a programme designed to meet the basin's demand for potable water in transferring water from other basins into the region. In addition to the dam on the Bouregreg River, projects are in progress to ensure a good water supply; raising the dam to increase its storage capacity and constructing two other small dams. The water quality of Bouregreg basin is monitored by a water treatment complex which supplies potable water to the neighbouring towns inhabited by more than 5 million persons. The greatest environmental problem in the basin is water pollution caused mainly by urban discharges and quarrying. A clean-up effort is underway, including a major project to collect in a single conduit all the domestic liquid waste from the towns of Rabat and Salé which is currently drained by 38 flood channels.

Rainfall is irregular in time and the impermeability of the surface of the basin leads to substantial losses in surface water. The quality of surface water in the downstream basin is threatened by agglomerations of habitations. Water resources which are limited over time and space are unevenly allocated, creating conflict among users.

Several actions will need to be initiated in order to develop water resources in the Bouregreg river basin and to achieve the following goals: socio-economic development of the local population; harnessing and developing its water resource quantity and quality, designing a water resources plan, integrating the various user sectors and lastly, comparing Bouregreg basin's water management and environmental issues with those of other basins. This will require research programmes, case studies, capacity building and rationalisation of human, material and scientific information resources.

The principal purposes of submitting the HELP proposal are to:

- improve the comprehension of quantitative and qualitative aspects of the basin water to respond more effectively to social demands and environmental requirement;

- develop a reflection on a preventive management strategy for extreme events (drought, floods);
- generate scientific and technical knowledge to aid the conservation and preservation of the environmental heritage and existing hydraulic infrastructures and help combat pollution;
- continue efforts towards improving water use efficiency and mobilisation;
- recognize the water demand and control its management;
- seek to match needs with available resources, by identifying water deficient areas and places with surplus capacity and design development scenarios within the current legislative framework;
- determine the potentials and development constraints of water resources;
- identify the different water uses and water users in the basin;
- map the results and establish recommendations to involve various stakeholders in the integrated water management process;
- determine the factors of degradation and quantify the related economic cost;
- recognise the actual and potential causes and risks of pollution originating from domestic, agricultural or industrial effluents;
- determine the current cost of water quality degradation and draw up recommendations for an action plan to mitigate the effects of pollution.

The principal output is the diagnosis of the basin containing the ecosystem components, the uses and resources, the changes and trends and an understanding of the links of the causes of changes, human activities and natural phenomena. This diagnosis will be an aid to understanding quantitative and qualitative aspects of the basin in order to reflect on a strategy for the sustainable management of natural resources. The means to achieve this are by researching and analysing available information, conducting further field and office studies in order to study some aspects in greater depth or to complete any missing information.

6. Statement of Proposed Activities

The aim of the proposed activities is to contribute to the integrated management of water resources in Bouregreg river basin by:

- defining the development potentials and constraints of the resource;
- identifying changes that have arise in uses and in biological resources;
- characterising the current state of the ecosystem and assessing modifications in these components;

- determining the current state of human activities and natural phenomena.
- incorporating this knowledge to make a diagnosis of the site which will serve as a basis for developing a framework for an Integrated master plan for integrated water management in the basin.

The specific goals are:

- identification of the different water uses and users in the basin;
- recognition of the potential causes and threats induced by pollution from domestic, agricultural or industrial effluents;
- mapping of the findings and formulating recommendations to ensure the involvement of the different stakeholders in the integrated water management process.

The notion of environmental damage is central to the concept of sustainable development. All economic activities have a social cost which corresponds to all the costs imposed on society. When the social cost is greater than the private cost, we speak about the existence of negative externalities. This external cost or damage to the environment may be caused by pollution or overexploitation of natural resources. If these environmental resources and the external costs they bear are not taken into consideration, the resources will not be efficiently allocated.

Environmental degradation may lead to disappearance or reduction of several values which are not normally confined to the market economy. The economic value of any damage, especially when linked to use values will also be assessed within the scope of this proposal so that it can be taken into consideration in the efficient and integrated management of the basin water resources. The specific goals of this evaluation are to know the actual and potential causes and threats generated by pollution from domestic, agricultural and industrial effluents so as to determine the current cost of water quality degradation and formulate recommendations for an action plan aimed at mitigating the effects of pollution.

7. Measurement and Reporting of Baseline Conditions in the Basin:

Any analysis must take into account the points of view of the different stakeholders within the framework of a fruitful and cooperative partnership if water resources management is to be improved. All stakeholders will be consulted during a judicious and impartial process which will mobilise the various points of view and build capacity to educate the actors on the pros and cons of the different options for water management. Community participation will help mitigate any differences or conflicts which may exist among water users and thus greater success in planning sustainable water management planning. Participatory workshops; interviews with experts or key decision-makers; informal meetings with users; consultations with opinion leaders; mobilising persons resources or influential and inspiring people; involving society in the process of mobilising stakeholders; taking account of the gender issue, etc., are just some of the points to consider when the public is involved in decision-making, implementing, monitoring and evaluating the integrated water management plan.

Programmes of capacity building which have been identified a priori include: training of managers from water management bodies; educating civil society and its different users on the principles of integrated water management; raising awareness in the community and among school children about the issues which threaten water sustainability, waste management and water pollution control, etc.

The proposed activities will be structured into three main parts: the documentation phase, the planning phase and the intervention phase. The documentation phase will consist of establishing the following: a complete list of the biological resource uses of the basin's territory; a summary document describing the changes over time and space of uses and biological resources; a document establishing linkages between modifications in the ecosystem and changes observed in uses and biological resources; a document describing the current state of evolution of each human activity and natural phenomenon, the links that exist among these activities and phenomena and the changes in the components of the ecosystem and a summary document incorporating these considerations to provide a diagnosis of the situation. A document will also be drawn up on the economic cost of water quality degradation in the basin.

The planning phase will entail drawing up one document focusing on existing and potential issues and conflicts in the basin and another one containing the action plan for sustainable and integrated water management. The action plan will be participatory and concerted, focusing on problems to solve, objectives to attain, partners concerned, procedure and estimation of financial resources needed for implementation along with sources of potential funding.

The third part is the intervention phase which consists of providing the necessary resources and monitoring the implementation of the action plan to evaluate whether or not the expected objectives have been attained. The functioning will be controlled and followed up by observing objectively verifiable indicators. These indicators will be based on the number of documents produced, the quality and consistency of these documents with the initial objectives outlined, the number of people or stakeholders who have been provided with capacity building for integrated water resources management.

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IMPACT OF THE IGNALINA NUCLEAR POWER PLANT ON THE DRUKSIAI COOLER-LAKE

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Abstract. Conflicts between nature protection and natural water resources exploitation arise only when intensive use of water recourses provokes stress in water ecosystems. In water management it is very important to define the ecological and human carrying capacity of water ecosystems. Determination of indicators helps to do this. That was one of the goals of the "Integrated Water Management" pilot study. Since 1984 the biggest Lithuanian Druksiai Lake has started to serve as a cooler for the Ignalina Nuclear Power Plant (INPP). The INPP operation has disturbed the natural hydrological and hydrothermal regime causing intensified evaporation and exerting impact on the lake hydrochemical properties. The above mentioned effects have led to irreversible changes in the unique lake ecosystem. The aim of this case study is to evaluate the changes in the lake ecosystem due to the impact of the nuclear power station. Water temperature is determined as an indicator of the effects in the lake ecosystem.

Keywords: water temperature; cooler-lake; nuclear power plant

1. Introduction

In most cases nuclear power plants are constructed close to large lakes, rivers, seas or oceans. Water bodies are necessary to cool overheated water discharged from power plants. Since 1984 the biggest Lithuanian Druksiai Lake has started to serve as a cooler for the Ignalina Nuclear Power Plant (INPP). This plant is located in the northeast corner of Lithuania, close to the borders with Belarus and Latvia. The Ignalina NPP has two RBMK-1500 reactors. At present, there

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are RBMK-type plants in Ignalina, Chernobyl, Kursk and Smolensk (Handbook About Ignalina Nuclear Power Plant, 1997). The first turbine of the NPP was put into operation in 1984 and the second one – in 1987. Their total capacity does not exceed 2500 MW. Cooling of one NPP unit requires 80 m^3/s of water from the lake. Monthly the lake receives 8.7×10^{15} J of heat on the average. Compared to the input water temperature water inside the condensers is heated by 10–12ºC; water temperature in the output channels is cooled down by 2–3ºC (Janukeniene and Jakubauskas, 1992).

It is planned to close the Ignalina NPP. The decommissioning of the first unit was done in 2005 and the second unit closing is planned for 2009. Accordingly, the state of the Druksiai Lake is going to change again as the cooling occurs. Therefore, this unique worldwide experiment may enable us to collect exclusive data that could be used to forecast lake conditions and design possible remediation measures for water bodies serving as coolers.

2. Case Study Description and the Decisional Problem

2.1. GEOGRAPHICAL DESCRIPTION

The Druksiai Lake-cooler of the NPP, the biggest lake in Lithuania, lies on the northeast border of Lithuania with Belarus (Figure 1). The area of the lake is 49 km^2, the maximum depth is 33.3 m, the average depth is 7.5 m and the total water volume is 369 million m^3. There are 11 tributaries to the lake and one river flowing out of it. The catchment area of the lake constitutes of 613 km^2. The watershed is dominated by a landscape with fluvioglacial and moraine drifts typical for the last ice-age and can be characterized as abounding in lakes and mainly small rivers.

2.2. PROBLEM

The main factors with an impact on the ecological state changes of the Druksiai Lake are the heated water outlet from INPP, i.e. changes of thermal regime and increasing of evaporation from the lake surface, and the inflow of sewage from Visaginas town (chemical pollution).

2.3. ENVIRONMENTAL CONSTRAINT

According to the Standards of Permissible Water Heating and Methodology of Temperature Control for the Druksiai Lake (1995), water surface temperature cannot exceed 28^{o}C in at least 80% of the total lake area.

2.4. INVESTIGATION OF THE DRUKSIAI LAKE

Research has been carried out by scientists from the Lithuanian academic institutions and from the Ecology Safety Service of INPP. During the period of 1979 – 1997 a group of scientists was engaged in a study of the Druksiai Lake. The most important parameters, such as water temperature, evaporation intensity, emissions and radionuclide accumulation in various components of the ecosystem, etc., were monitored to evaluate the changes in the lake before and after the INPP construction. The environmental monitoring at INPP was carried out in conformity with the legislation of the Republic of Lithuania and the Environmental Protection Policy.

2.5. DECISION MAKER

In order to limit the impact on the environment, the INPP is operated in accordance with the “Permit to Use Natural Resources”. The INPP authority is the decision maker concerning the work regime of the plant and contamination of the Druksiai Lake.

2.6. CONTROLLING THE STATE OF THE DRUKSIAI LAKE - ONE OF THE DECISIONS FOR SOLVING THE PROBLEM

The investigation of the present ecological state of the lake is not sufficient. The participation of scientists is not active enough with respect to the absence of scientific research programs. Environmental protection monitoring at INPP is concentrated on the research of radioactive and chemical contamination of the lake. The determination of an ecological indicator as water temperature could help to define the ecological state of the Druksiai Lake.

3. Methods and Results

Looking for the indicator of the Druksiai Lake, temperature database of the lake water has been created and the water balance of the lake has been calculated.

3.1. THERMAL REGIME OF THE DRUKSIAI LAKE

The Laboratory of Hydrology of the Lithuanian Energy Institute investigates the hydrologic and hydrothermal behavior of the lake for a long time. A great amount of data has been collected: information about lake water balance elements like inflow, outflow, precipitation and evaporation, as well as water surface and volume temperatures. The water temperature data owned by the laboratory was accumulated sequentially during 18 years (1981−1998) under wide range of different weather and INPP capacity conditions. A computer database of the Druksiai Lake thermal regime was created. It consists of tabular data and digital maps. Tabular data include lake surface (Figure 1) and air temperature, overheated lake surface area, wind speed and INPP operating capacity on the expedition day (Table 1). Digital maps were developed interpolating the point data of the lake surface temperature. Fifteen lake surface thermal maps of natural regime were created during the period of 1981−1983 before the INPP operation and 137 lake surface thermal maps represent the cooler-lake state.

The highest natural temperature of the lake surface is 25.5ºC (Gailiusis and Virbickas, 1995). The highest cooler-lake annual water temperatures are presented in Table 1.

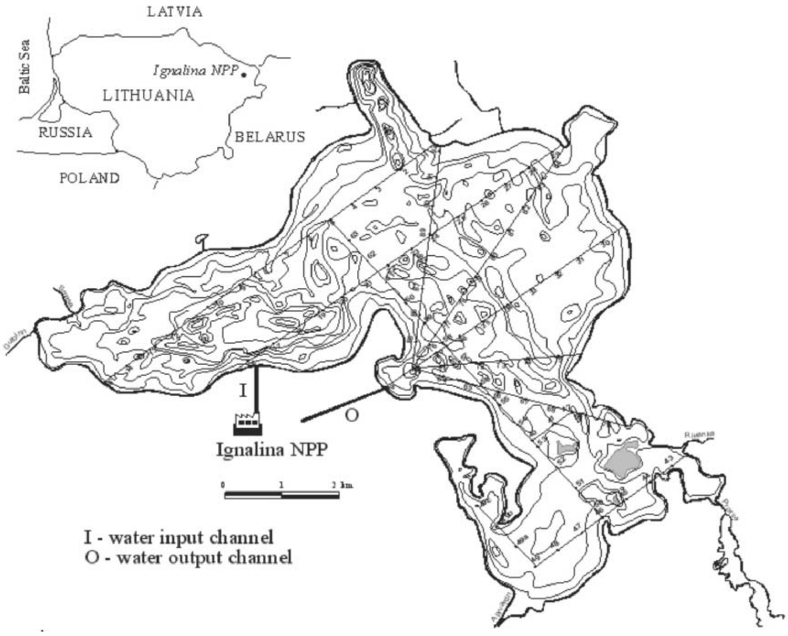

Figure 1. The INPP location and the lake water temperature measurement sites scheme

The hydrothermal regime of the Druksiai Lake was changed when it became a cooler for the Ignalina NPP. The discharged effluents have risen the average monthly temperature of the lake by 3–4 degrees (Figure 2). In general, the distribution of the overheated water is uneven and depends on the particular conditions (Sarauskiene, 2001).

The lake water balance has been calculated for many years. According to the data, evaporation from the lake has increased by 49% on the average due to the impact of INPP (Table 1–3). The operation of this plant has disturbed the heat balance of the lake and affected the lake hydrochemical regime. The above mentioned effects have led to irreversible changes in the unique lake ecosystem.

TABLE 1. Database records for cases when the lake was extremely overheated

Date	Lake surface temperatures, ºC			
	Highest in the outlet	500 m from the outlet	Lowest	Average
09 08 1984	30.3	30.0	23.9	25.4
26 06 1985	32.5	31.5	21.5	23.5
18 06 1986	33.4	33.2	23.6	26.8
15 07 1988	36.6	36.2	27.0	30.1
12 07 1989	32.5	31.9	23.1	25.3
10 08 1990	32.6	30.7	20.3	21.6
04 08 1991	35.4	34.2	23.6	25.5
01 06 1992	30.5	29.8	19.2	21.5
05 08 1994	31.1	31.0	26.3	27.3
22 08 1995	32.8	31.6	24.0	24.4
23 08 1996	35.0	34.2	21.3	24.0
06 07 1997	32.5	31.7	22.6	24.1
06 06 1998	32.1	31.5	21.7	22.7

TABLE 2. Database records for cases when the lake was extremely overheated, continuation

Date	Overheated lake area, %		INPP operation capacity, MW	Air temperature, ºC
	> 25.5 ºC	> 28 ºC		
09 08 1984	50	6	796	21.4
26 06 1985	12	5	1505	19.8
18 06 1986	66	24	1490	25.5
15 07 1988	100	86	2447	25.9
12 07 1989	34	8	1264	22.5
10 08 1990	8	4	2500	18.5
04 08 1991	31	11	1296	25.8
01 06 1992	11	2	1243	23.6
05 08 1994	100	38	759	25.0
22 08 1995	41	11	1293	21.5
23 08 1996	13	7	1272	25.5
06 07 1997	4	3	747	22.1
06 06 1998	25	17	1306	24.0

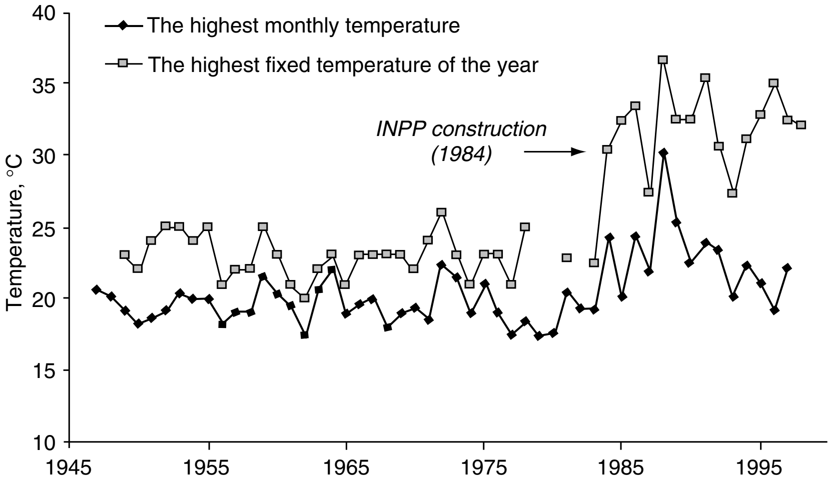

Figure 2. Surface water temperatures of the Druksiai Lake before and after Ignalina NPP started to operate

3.2. CHEMICAL POLLUTION

The changes in the hydrochemical state of the lake confirmed the INPP impact on the Druksiai Lake ecosystem. The trophic state of the lake can be described by the ratio between the total concentrations of nitrogen (Nt) and phosphorus (Pt). If this ratio is less than 10, the state of the lake changes from mezotrophic to eutrophic. The Druksiai Lake was a mezotrophic water body before the intensive anthropogenic influence; the ratio was over 10. Such quantitative changes of nutrients indicate the changes in the trophic state of the lake.

TABLE 3. Average values of evaporation from the lake surface in 1973-1996

	Months						Sum
	V	VI	VII	VIII	IX	X	V-VIII
Before construction of the Ignalina NPP, mm (till 1984)	62.14	94.82	107.79	107.30	84.50	59.01	372.05
After construction of the INPP, mm (since 1984)	103.63	141.33	154.17	158.15	117.26	77.54	557.28
Losses of evaporation, mm	41.49	46.51	46.38	50.85	32.76	18.53	185.24
%	67	49	43	47	39	31	49

The ratio began to decrease in 1991 and approximated the characteristics of an eutrophic water body since 1995 (Nt/Pt ratio less than 10) (Figure 3). Permanent chemical pollution by municipal wastewater and thermal pollution from INPP are the main reasons for the occurring trophic status changes in the Druksiai Lake.

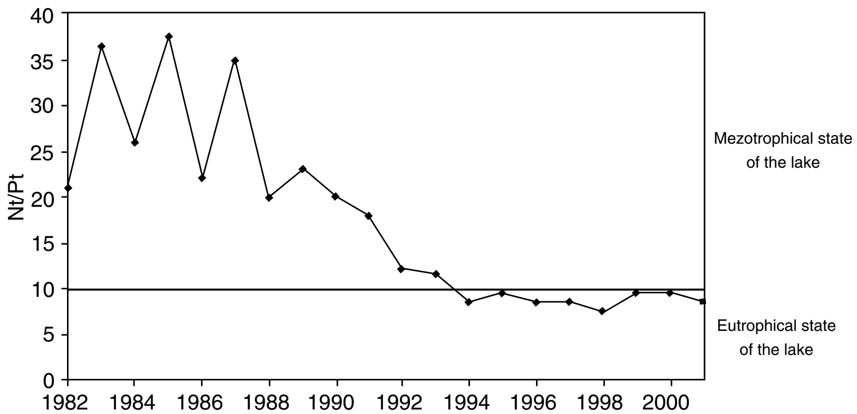

Figure 3. Ratio between the average concentrations of total nitrogen (Nt) and total phosphorus (Pt) in the lake (Salickaite-Bunikiene and Kirkutyte, 2003)

3.3. ECOLOGICAL CHANGES

Before the Ignalina NPP construction the Druksiai Lake was a mezotrophic water body displaying features of oligotrophy. The cryophilic and eurythermic organisms dominated in the biota composition (Gailiusis and Virbickas, 1995). The present state of the lake biota is unstable, and it is adapting itself to the new conditions through its generic composition. Now trophic status changes are taking place in the lake. After the INPP construction a number of zooplankton species were decreased. Eurytermic and stenothermic thermophylic species prevailed in the planktonbiocenosis. *Copepoda* and *Cladocera* dominated in metazooplankton. *Rotatoria* were abundant only in the shallow and heated water outlet area. *Mollusca* sprung up after the INPP construction (Figure 4) (Lithuanian National Scientific Programme, 1997).

Before the INPP construction smelt and vendace prevailed in the fish community of the lake. The optimal water temperature for these fishes is < 12–15°C (Gailiusis and Virbickas, 1995). After the INPP construction the average monthly temperature of the lake raised by 3–4 degrees. This is the reason for the changes

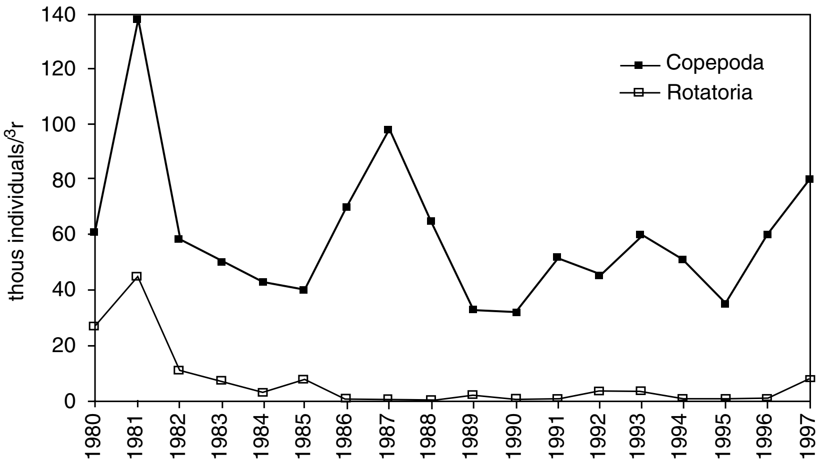

Figure 4. Changes in the quantitative structure of metazooplankton (strength, thousand individuals/m³) in the summer period

in fish composition of the lake. Now roach is prevailing in lake water. The changes in fish composition provide evidence for the changed state of the lake from mezotrophical to eutrophical.

4. Conclusions and Future Developments

The successive changes in the Druksiai Lake ecosystem have been defined for the period of exploitation of the Ignalina Nuclear Power Plant. One of the reasons for these changes is that the cooling water has risen the average monthly temperature of the lake by 3–4 degrees. The effect of the artificial changes in the water temperature is especially great for lake hydrobionts. Some of the species can tolerate an additional amount of heat, while for the others it presents a threat for existence. The successive changes of ecosystem would not occur further if the average water temperature of the lake could not exceed more than 24.5°C.

Water temperature of the lake can be used as an indicator of the Druksiai Lake ecological state. The performed investigation on the lake thermal regime and the developed computer database could enable the upgrade of the Environmental monitoring at INPP in order to improve the evaluation of the lake state. In addition, the ecological modeling of the Druksiai Lake could be done on the basis of this investigation. The modeling would allow the evaluation of the processes in the lake after the decommissioning of INPP.

Acknowledgements

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TRANSBOUNDARY RIVER CONTRACT SEMOIS-SEMOY BETWEEN BELGIUM (WALLONIA) AND FRANCE

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Abstract. Through dialogues between partners, a river contract intends to develop and restore the multiple functions and uses of water in answer to the needs of a community of users. Under this scheme, both government and private-sector players commit themselves by means of a contract to implement a consensus action programme to restore the river and its drainage basin's water resources. Information and awareness campaigns are added to concrete actions of waterway development and different sorts of work connected to water. The river committee is a place for democratic speech where the familiar rubs shoulders with the institutional, where citizens meet operators, where the life forces of society are finally brought together to take charge of their river's future and their relationship with the river. In this way, a joint project has been bringing together Belgian and French protagonists since 1999, trough the Interreg II and Interreg III operational programmes. They work now together in a joint management of the river and its tributaries, this time on the scale of the entire Semois-Semoy hydrographical subdrainage basin. This article describe the concept and the methodology of this concrete transboundary collaboration, the results and the perspectives.

Keywords: river contract; drainage basin; participative management tool; stakeholders; action programme; local level; transboundary project Interreg III

1. Introduction

Belgian Semois and French Semoy Two different names for a same river, and for a same drainage basin subject to a joint management approach, referred to

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as the River Contract. This participative management tool in the area of water leads to the implementation of an action programme, at local level, geared to restoring watercourses and water resources with reference to the guidelines defined by the river users of the two countries. Various fields of intervention are concerned, such as water quality, development and management of watercourses, economic activities, tourism and leisure, enhancement of heritage, etc.

The originality of the method is certainly the extensive consultation among players involved, the decision-making process based on the search for consensus and, lastly, the means used to organise expertise. By enlarging the partnership from one country to another, this overall management approach focused on the drainage basin offers a space of upstream and downstream co-operation and dialogue. It is also a new way of communicating, informing and raising awareness among inhabitants and stakeholders within the same drainage basin.

For five years, the innovative character of the Semois/Semoy Transboundary River Contract has been instrumental in mapping out channels of possible collaboration at the service of Community water policy within Europe of the Regions.

2. Case Study Description and the Decisional Problem

2.1. FROM SECTORAL MANAGEMENT TO A PARTICIPATIVE APPROACH

In Belgium, it is worth recalling that one of the outcomes of the country's devolution is that water policy was entrusted to the three Regions, namely Wallonia or the Walloon Region, Flanders or the Flemish Region and the Brussels-Capital Region. Only Wallonia, the instigator of the project presented herein, is concerned. In the Walloon Region, a sectoral approach permeated water management for a long time. That sectorisation could be explained by a fragmentary legislative and administrative approach specific to each sector. The result of that was highly compartmentalized, use-focused management organized in a channel structure along technical and administrative management lines.

New demands have arisen in that context over the last ten years. Those demands, expressed by various players in the water management field but also by the stakeholders of civil society, revealed a need to break with the conventional management method. Two of those new demands further consolidated the desire for a concerted approach:

- on the one hand, the increase in the functions and uses of water, especially in the recreational sector, leads to increased pressure on resources by creating user conflicts;

- on the other hand, the population is increasingly sensitive to the various problems connected with water quality and environmental protection. This awareness leads users and civil society to demand that they participate in water-resource decision making.

Furthermore, this trend towards participative management in the environmental field has been strengthened by recognition at the highest level of the international community. We need only recall principle 10 of the RIO declaration: "Environmental issues are best handled with participation of all concerned citizens, at the relevant level". According to Duran (1999, quoted by Allain, 2001), "participative management developed to meet shortcomings in methods of traditional political regulation and in a new conception of public action in terms of collective action". River contracts find their source in this context at both international and local level.

2.2. THE RIVER CONTRACT, *MODUS OPERANDI*

The scenario of a river contract is simple and complex at one and the same time: to bring together all the partners concerned by the river around a same table with a view to restoring the river. This transversal and multidisciplinary approach integrates all the problems connected with water resources and aquatic environments in areas as varied as the qualitative and quantitative aspects of water, hydraulic aspects, town and country planning, nature protection, economic activities, heritage, etc. Beyond the defining of management objectives and guidelines, the contract involves a programme of concrete actions which benefit from the ongoing contribution of local expertise. These accomplishments are implemented by permanently mobilizing local players in a framework of concerted action and consensus decision making. These operating conditions are actually the strong point of the River Contract, which should firstly be understood as a participative approach at local level.

Representatives of the public and private players involved in this project are brought together within a river committee, considered as a space of meeting, dialogue and expression open to everyone. This committee is composed of 80 members representing local authorities, administrations, users and NGOs.

River contracts were initiated in France 10 years earlier than in Wallonia. From 1981, a ministerial circular established the French river contract model. That took over from the "Clean Rivers" contract operations. At the outset, they were presented as instruments for drawing up Departmental maps of quality objectives and increasingly evolved to take the environment and uses into account.

In Wallonia, the first river contract experiences, inspired by the French approach, developed at the beginning of the nineties. In 1993, institutional recognition, in the form of a first ministerial circular relating to the conditions of acceptability and the procedures for drawing up river contracts, introduces this type of management as a new instrument of implementation of water policy in the Walloon Region.

If the river contract is recognized both in France and in Wallonia as a concerted management tool and the expression of local dynamics in the water sphere, its application differs appreciable from one country to the next (see Figure 1). In both cases, this approach calls for voluntary contractual processes and is situated parallel to already existing management procedures rather than as a replacement for them.

Characteristics	France	Wallonia
Legal basis	Ministerial circular (1981) confirmed by the Water Act, dated 1992 Ministerial circular (1993) Ministerial circular (1994)	Ministerial circular (1993) confirmed by New ministerial circular (2001)
Principles	Intervention tool unites actions in favour of overall river management	Guideline and intervention tool and memorandum of understanding on objectives expressed in an action programme
Methodology	Co-ordinated management among various public managers	Concerted management among all users and administrations
Practice of consensus building	Timid, apart from institutional players	Extended to users, associations, and riverside residents
Type of approach	Voluntary	Voluntary with moral commitment Non-restricting
Co-ordination	Not planned at the outset but often implemented	Planned funded by public partners
Procedure	Approval summary dossier Prefectorial Decree by the River Committee Approval final dossier by the Ministry of the Env. Signature and implementation	Preparatory dossier Study agreement Setting up the River committee and preparation of the draft contract Approval by the River committee Signature and implementation
Planned duration	Development: 2 to 3 years Application: 5 years	Development: 3 years Application: per 3-year period (max: 12 years)
Status of the underlying structure	Steering committee: Intermunicipal structure that assumes project ownership	River committee: consultation body does not assume project ownership
Source of funding in the implementation of actions	Public co-financing programme: fruit of a financial arrangement between the various institutional levels and the Water Agency	Each partner signatory to the contract assumes the funding of the actions concerning it
Management unit	subdrainage basin, portion of subdrainage basin, embayment	subdrainage basin
Integration with other management tools	SAGE (SDAGE) in connection with the Water Framework Directive	Subdrainage basin plan (end 2005) in connection with the Water Framework Directive
Involvement of local authorities	Generally strong through an intermunicipal structure	Variable according to the extent of their commitment in the study and monitoring agreement
Involvement of users and associations	Poor	Generally strong (variable from one contract to another)
Progress	Approximately 120, including 31 completed contracts	15 River contracts at various stages of completion

Figure 1. Some elements of comparison between France and Wallonia concerning the river contract approach

Concerning the Semois transboundary subdrainage basin, the first River contract was implemented on the Walloon side in 1996, after a 3-year preparatory phase. A few years later, the partners of the French Semoy mobilized within the framework of a European cross-border cooperation programme.

In this way, a joint project has been bringing together Belgian and French protagonists, since 1999, so as to work together in a joint management of the river and its tributaries, this time on the scale of the entire Semois-Semoy hydrographical subdrainage basin (see Figure 2).

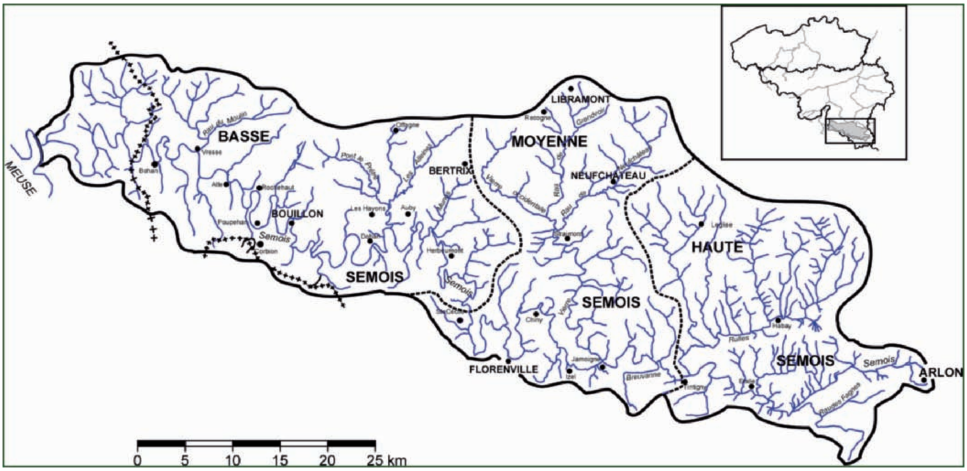

Figure 2. Concise presentation of the Semois-Semoy transboundary basin

Some features:
Source: Arlon, town with 24,000 inhabitants located in southern Belgium
Confluence with the Meuse: Monthermé, France
Length of the watercourse: 210 km
Average flow: 30 m³/sec
Area of the drainage basin : 1,329 km²
Population : 75,000 residents
Pollution load: 125,000 EH
Main economic activities: farming (livestock), forestry, tourism, recreational activities, small family businesses in Wallonia, metallurgical industrial activities in France

3. Methods and Results

3.1. THE EUROPEAN INTERREG II AND III PROGRAMMES AT THE SERVICE OF CROSS-BORDER EXPERIENCE

The two river contracts, at different stages however, were able to be associated for the first time in a cross-border project through the INTERREG II Wallonia/ Champagne-Ardenne operational programme. The objective sought through that first experience was to bring the Belgian and French experiences closer together in the implementation of a programme of joint actions. That programme was spread over a period of three years (1999-2001), corresponding on the Walloon side to the application of the first contract signed in 1996 and, on the French side, to the drawing up of the final dossier completed at the end of 2001. The transboundary contract was signed in September 2002. It contained a Walloon part (corresponding to a second action programme) and a French part (the first Semoy contract).

As a result of the success of Interreg II, the experience was renewed within the framework of the following programme, INTERREG III France – Wallonia – Flanders, covering the 2003-2005 period. That new commitment led to a series of joint actions to be included in the river contracts and they are currently being implemented.

On the Walloon side, the *Fondation Universitaire Luxembourgeoise* (Luxembourg University Foundation) (now integrated into the Department of Environmental Science and Management of the University of Liège,) is in charge of co-ordinating that project. It is accompanied in the implementation of the actions by various local players (associations, tourism entities, municipalities, etc.). On the French side, the operator is the *Communauté de communes de Meuse et Semoy*, an intermunicipal structure grouping several municipalities.

The meeting of the two parties takes place through a transboundary support committee, which is required to draw up half-yearly reports on the progress of the programme. Specific work groups were set up according to the actions to be developed and those groups regularly associate French and Walloon partners.

Lastly, this action programme is partly funded by the European Community through the ERDF/FEDER (European Regional Development Fund), by the French authorities (State, Region, Department, Water Agency and Local Authorities) and the Walloon Region (Municipalities, Ministry of the Walloon Region, Walloon Ministry of Infrastructure and Public Works).

3.2. RESULTS

The action programme forming part of that transboundary project concerned concrete accomplishments in particular, carried out on both sides of the border. As examples, we can mention ecological developments of watercourses, the creation of spawning grounds, the restoration of old dams, landscape enhancement, secondary valleys restorations, educational activities, activities to enhance tourist appeal, development of leisure fishing and the drawing up of a fish breeding management plan and the publication of a Semois/Semoy transboundary periodical in the form of a partner's liaison newsletter.

All those accomplishments are the expression of the pragmatic side of the approach and form the best evidence of the high profile given to the project. Besides the work and the activities carried out, this experience relies on an ongoing exchange of know-how involving various methodologies and thematic approaches between the two countries. It enables the expansion of a network of co-operation together with a rapprochement between administrative or field players. In the end, this project aims to develop lifelong drainage basin solidarity through integrated and consistent upstream/downstream solidarity and the development of a feeling of belonging to a same entity. Furthermore, the rapprochement of the two parties is financially interesting through the sharing of costs for joint actions (studies, production of brochures, etc.), which makes it possible to consolidate the information and awareness-raising aspects in particular.

4. Conclusions and Future Developments

This contractual method of water management is meeting with increasing success among users and local authorities. This river contract experience shows that its application can be extended to the management of transboundary sub-drainage basins while offering an organisational framework for water resources.

In actual fact, the transboundary dimension of water management is increasingly a national policy issue. Is it not true to say that the territory of the European Union is divided into a majority of international river basins? Many international commissions have been set up at river level. Furthermore, Article 13 of the Directive 2000/60/EEC from the European Parliament and Council, setting out a framework for Community water management policy, lays down that Member States shall endeavour to produce a single river basin management plan for an international river basin district. That same Article states that river basin management plans may be supplemented by management plans for sub-basins. Why not therefore produce transboundary sub-basin plans?

The concrete expression of the new European water policy can only be strengthened by initiatives at sub-basin level complementing and interconnecting international programmes at river basin level. Should not the Semois-Semoy experience presented herein be seen as an invitation to declare that European water policy will also be formed at local level?

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GROUND AND WATER LEVELS CHANGE IN THE SCHELDT BASIN

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Abstract. The Scheldt watershed is a transboundary hydrosystem which extends on three countries (France, Belgium and the Netherlands). It is characterized by a very strong urbanization and a very strong hydrological artificialisation both in surface and underground dynamic flows. These human impacts are already very present in the upstream basin (in France) as well as their downstream consequences in Belgium and in the Netherlands. In France, one of the main issues relates to the relative variations of water (surface and underground) and ground levels including their consequences in quantity (i.e. floods and low water periods), in quality (i.e. pollution of surface and ground waters) and their socio-economic impacts. This paper expose and analyze the upstream case study in the perspective of the hydrological link at basin scale.

Keywords: Scheldt, transboundary basin, surface and groundwater levels, urbanization, demographic pressure, intensive agriculture, heavy industry, France

1. Introduction

The Scheldt basin is a littoral plain (Flanders) where valleys are broad and flat-bottomed. This topography has always supported the establishment of populations and socio-economic activities. Nowadays, the Scheldt watershed is a very high density populated area which gathers nearly six million inhabitants divided on three countries (Figure 1): France (upstream), Belgium and the Netherlands (downstream), for an approximate surface of 22100 sq.km.

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In this transboundary context, there's an old population establishment supported by water proximity. However, during the twentieth century, demographical growth and technological progress (i.e. drainage, agricultural productivity and civil engineering) developed a continuous urbanization along rivers and infrastructures (i.e. canals, railways and roads). For lack of real physical constraints, urban development has increased human impacts in the valleys, the mining area and the surrounding of the communication nodes. This concentration of population and economical activities has developed a territorial and hydrological vulnerability. But the human pressure on the hydrosystem functions impacts both society and ecosystems (Meire et al., 1998). In this context, environmental risks (i.e. climatical, industrial …) generate many complex stress situations for the population (i.e. floods, health …) and the "nature" (i.e. biodiversity regression, ecological good and services reduction …).

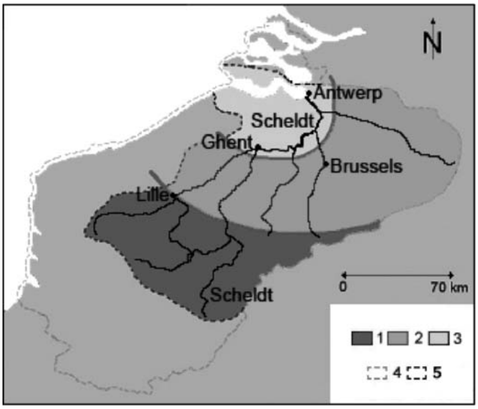

Figure 1. The Scheldt basin

Key: 1 upstream zone (France and Belgium), 2 medium zone (Belgium), 3 downstream zone (Belgium and the Netherlands), 4 Scheldt district (International), 5 Scheldt basin (International).

To reach the 2015 objectives fixed by the European Water Directive, the Scheldt basin has been enlarged to a Scheldt District that includes the surrounded watersheds which are already managed by the administrative regions in charge of the Scheldt basin (SCALDIT 2004).

2. The Impacts at Basin Scale

At basin scale, several socio-environmental stakes result from the extreme territorial artificialisation (i.e. canals, polders, urbanization, intensive agriculture …) of the hydrosystem. Consequently, the relationship between the society and its environment is strongly degraded. The awareness of being part of a complex water system in permanent dynamic balance is very thin and there's a real lack of territorial knowledge concerning the water system functionalities and dysfunctionalities. Thus, the balance between the hydrosystem carrying capacities and the socio-economical dynamics is badly evaluated (Meilliez 2003), even for goods and services that could be given by the water system itself (i.e. flood peak reduction, denitrification …).

From an ecological point of view, the hydrosystem is clustered by infra-structures (i.e. canals, roads, railways …) and urbanization (i.e. waterproofed and/or polluted surfaces) and the evolution of agricultural practices (i.e. drainage or land consolidation, use of fertilizer and pesticide ...). The consequences strongly impact the natural water system balance for quantity (i.e. water, sediment and pollution flux) and quality (i.e. eutrophization, nutriment cycle …).

From a health-environment point of view, conurbation develops on its own water resources. The draw off and effluent management does not take sufficiently in account the ground and surface water vulnerability to domestic pollution. Only 54% of the population is connected to a collective water treatment plan (SCALDIT 2004). That situation leads to a quality deterioration of the available water for drinking, industrial uses and ecological needs (ICBS / CIPE 1994).

From a demographic and socio-economical point of view, the population should exceed the 8 to 9 million inhabitants at the end of the 21st century. This pressure will increase the society's impact among the environment and specially among the hydrosystem functionalities.

Lastly, the regional planning of the NO Europe crossroads, where populations, activities and communication networks (rail, road, waterway) converge, intensifies goods and people mobility (intermodality) but also the impacts against the Scheldt hydrosystem.

3. The Upstream Case Study

According to the INSEE (Census 2000) the population has reached 3.1 million inhabitants in 1999 in the french upstream part. Over the period 1982-1999 the net increase remains very weak (i.e. 1.7%). But at the same time the population concentrates around the high density urban areas and transportation axis (figure 2). The thirty one densest cities (> 2500 inhab./sq.km) gathers nearly a third of the total population (960000 inhab.) for an average density of 4960 inhab./sq.km. This demographic pressure on the Scheldt upstream part and this densification process are due to the unactractivity of the old coal basin zone which was heavily affected by the socio-economical effects of the mining stop (Meilliez 1998-a) during the 80's.

In the urban areas, strong population densities, massive ground water proofing and industrial activities (i.e. energy, steel industry, chemistry …) constitute a significant source of surface water pollution (Meilliez, 1998-b).

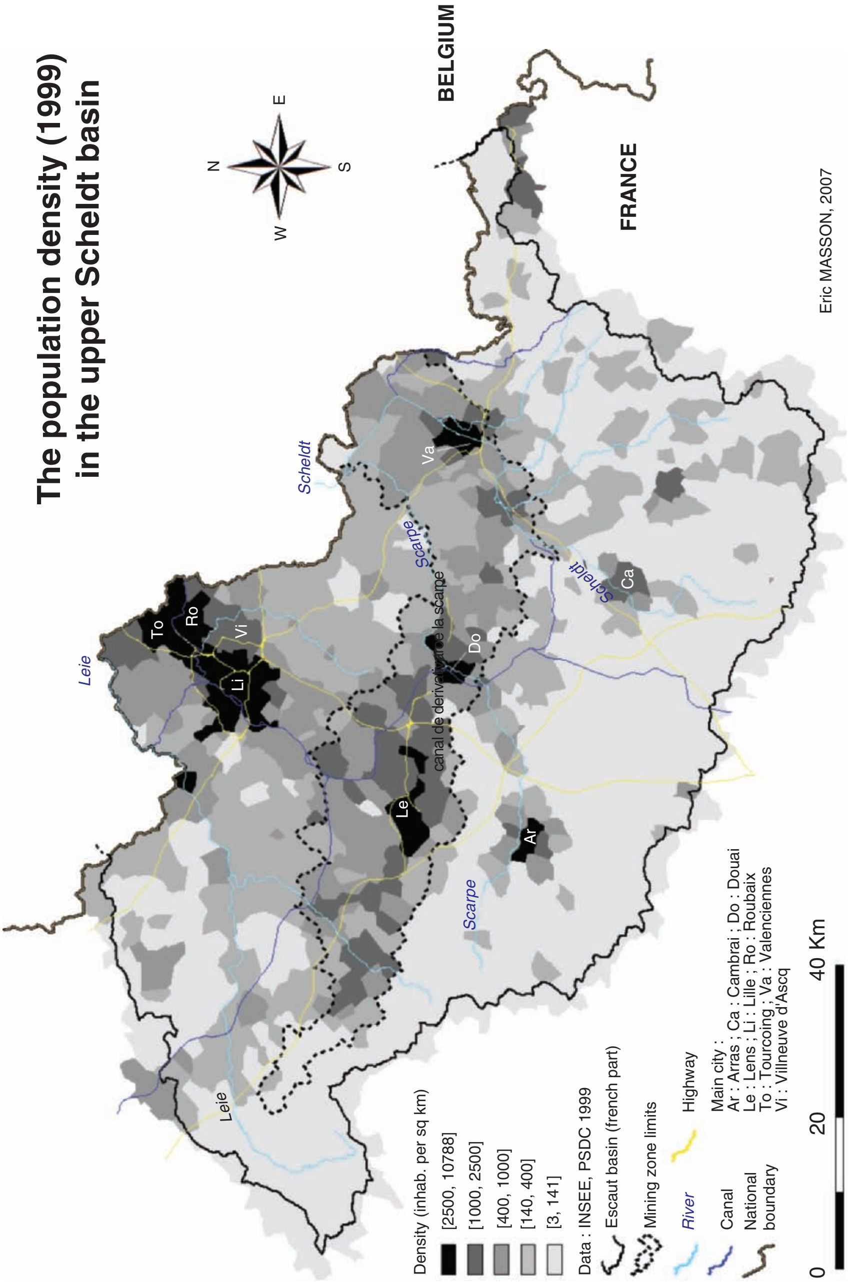

Figure 2. The population density in upper Scheldt basin

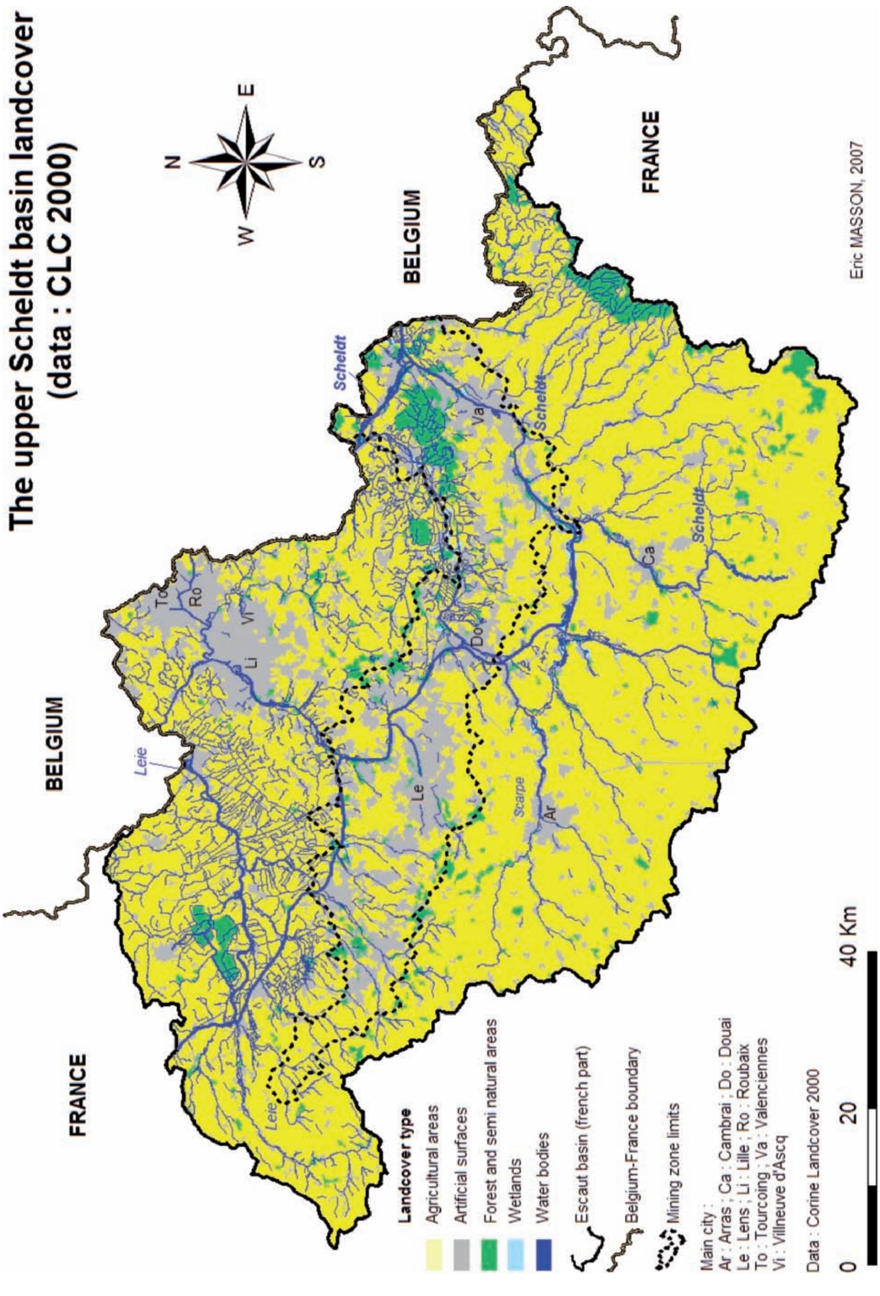

Figure 3. The upper Scheldt basin landcover

In the rural areas (SCALDIT 2004), intensive crops fields cover a majority of land use and contribute of this fact to a large input of various diffuse pollutions (i.e. fertilizers, pesticides ...). Located in the upstream sectors, it is strongly contributing to the ground and surface water pollution by wash-off and infiltration. But downstream sectors (Belgium and the Netherlands) share the same hydrosystem which is gradually polluted from upstream inputs in the head of the basin to the Scheldt estuary. Moreover, the waterproofing of downstream sectors by the geological formations (Quaternary and Tertiary) limits fresh water infiltration and the possibility of a pollutant concentration decreasing.

Although the mining activity has stopped since the 80's, the extraction waste stills pollute soils and ground water (S. Denimal et al. 2001) by infiltration and groundwater level rising through the extraction networks and the mining wells (S. Denimal et al., 2001). It is a very important issue in the Scheldt transboundary context because groundwater is a shared resource at basin scale. In addition, the consequences of consecutive ground collapse due to the ending of the mining activities have several environmental effects in the coal basin zone (Meilliez 1998-c). In this area of strong population density and of demographical and industrial regression, the consequences are:

- a strong water pollution by waterproofed surfaces wash-off;
- a strong ground water pollution due to the mining polluted soils proximity;
- an increase in flooding frequency and intensity due to a ground level subsidence;
- an increase of socio-economic impacts and environmental vulnerability due to a non integrated environmental management.

All these consequences result from a heavy humanized territorial management that remains since the upper areas of the Scheldt basin (figure 3 and table 1). The CLC 2000 data (first level) clearly give a broad overview of this human impact. Agriculture (i.e. Arable land, Permanent crops, Pastures …) and artificial areas (i.e. urbanisation, industrial, commercial and transport units, mine, construction sites …) totalize 94.5% of the total upper Scheldt basin.

TABLE 1. Land cover distribution in the upper Scheldt basin (French part): Data: CLC 2000, EEA

CLC 2000 Type	**Value in %**
Artificial surfaces	17
Agricultural areas	76.5
Forest and semi natural areas	5.9
Wetlands	0.4
Waterbodies	0.2

The three main land-cover classes (level 3 – CLC 2000) are in fact arable land (64%), discontinuous urbanization (13%) and pasture (9%). This three points reveal the spatialization of pollution sources in the upstream part of the Scheldt basin: agriculture, domestic waste water (only 56% houses are connected to a collective treatment plan) and breeding effluents. But it doesn't reveal the industrial and the waterproofed surfaces (roads and continuous urbanized areas) impacts which are also very significant in the global consequences of land use and water management (ICBS / CIPE 1994; SCALDIT 2004).

4. The Surface Water, Ground and Groundwater Issues

In this case study, any relative modification of water (i.e. surface and/or groundwater) and ground (i.e. mining subsidence, sedimentation, isostatic readjustment) levels constitutes an environmental pressure at basin scale between the upstream (France), the median (Belgium) and the estuarian (Belgium and the Netherlands) sectors. To carry out an integrated Scheldt water management, it is thus necessary to answer several questions (figure 4):

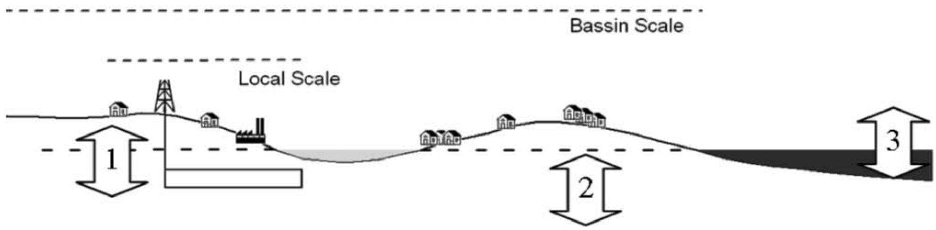

Figure 4. Ground and water level change in the Scheldt basin

Key: 1 groundwater level, 2 ground level, 3 base level.

- Which phenomena, natural and anthropical, contribute to the ground level mobility (Meilliez 1998-c) ?
- • Tectonics whose dynamics is slow at lithospheric scale (10^6 years).
- • The erosion/sedimentation system which relates to the problems both at space and time scale:
- 1 to 10^2 years for the hydrographic network
- 10^3 to 10^5 years for the Scheldt basin.
- • The underground subsidence that can be observed in the coal mining and the chalk quarries zones which are very localised with a spatial of 1 to 10^2 sq.km and temporal of 1 to 10^2 years scales.

- The consecutive isostatic readjustment due to a mass deficit created by mining activities at regional scale with a time step of 10^2 years.
- Earthworks and agricultural technics which increase erosion and hydrographic networks silting (i.e. “natural” rivers, waterways ...). Their impact relates to restricted surfaces (1 to 10^3 sq.km) running on a time step of 1 to 10^2 years.

- Which phenomena contribute to the surface water level variations ?

- variations of marine level (i.e. global change, storm surge …) which impact the hydrographic network level basis and the coastline evolution at regional scale with a 10^2 to 10^5 years time step.
- regional rainfalls pattern which conditions water inputs in the catchment’s area, the groundwater level at regional scale with a 10 years time step.
- draw-off which conditions ground and surface water levels at local and regional scale with a short term time step (i.e. seasonal to a few years).
- land use which conditions infiltration/wash-off at local scale with a 1 to 10 years time step.
- regional groundwater level variations involving a capillary water lost above the unsaturated zone. The same phenomenon currently occurs in consequence of a carboniferous grounds hydraulic rebalancing (natural filling of a man created aquifer in the mining zone) at a regional scale with a 10^2 years time step.

These level variations between ground and water result from many natural and non natural processes that are in fact inter-active and interdependent at various space-time steps. Many gaps of knowledge have to be fixed to cope this complexity and understand witch are the key decisions in the Scheldt water management that could affect the mid and long term water system evolution.

The society developed in the Scheldt basin is only sensitized (but roughly) with the direct consequences of these phenomena (i.e. pollution, floods, channels silting ...). For the three countries (i.e. France, Belgium, Netherlands), causes and impacts on the hydrosystem functionality and its ecosystem (i.e. biodiversity, habitat quality ...) are not sufficiently taken into account in the territorial governance and the land-use management plans at basin scale (Kergomard 2004).

5. Building a Scientific Expertise at Basin Scale for a Scheldt Integrated Water Management

The objectives to be reached concerning a Scheldt hydrosystem integrated management follow those defined by European water directive. It supplements other environmental management directives (i.e. nitrate, waste …). This water directive defines the european legal framework and the objectives to be reached in 2015. It fixes the acceptable limits for pressures applied against water quality and quantity and its availability for populations, activities and “natural” environment. However, strong environmental impacts have already been identified in the Scheldt hydrosystem (ICBS / CIPE 1994; Meire et al. 1998; SCALDIT 2004) and seems to be not reversible any more (i.e. harbor activities in Antwerp, Ghent-Antwerp waterway dikes …) specially for the Scheldt’s estuarine ecosystem (Meire et al., 2005). As the Scheldt basin extends on one of the most industrialized European area (ICBS/CIPE 1994; SCALDIT 2004), the economic pressures are very high and politically sustained. To give an example, the french part of the Scheldt basin hardly leaves its metallurgical and textile industrial conversion. In the old mining zone, the rate of unemployment is higher than the national average. This leads state and local communities to develop economic activities (Meilliez 1998-c) and housing that indeed maintain the human pressures on the hydrosystem and feeds the downstream pollution transfer. The political pressure is also very present in this transboundary context. In fact, the Scheldt basin governance deals with various decision makers (Meire et al., 2002) from state to local levels within three countries (figure 1). Even for the French part (Kergomard 2004), decision making belong to a complex hierachical pool of actors (i.e. state, regional and local communities) in relation with the Artois-Picardie Water Agency (in charge of french part of the Scheldt district) to fulfill the EC water directive (i.e. SCALDIT project) and other EC directives related to the environmental quality and integrity (SCALDIT 2004). The decisions are not efficiently applied by all the actors at local level and by the population at individual level. Indeed, building an Integrated Water Management plan at Scheldt’s basin scale requires a scientific expertise to cope the hydrosystem complexity and help the decision makers in the evaluation of the numerous stakes of ground and water levels change.

6. Conclusions

For the French part of the basin, previous results have already focused on the environmental (SCALDIT 2004; ICBS/CIPE 1994; Meilliez 1998a, 1998-b; Denimal et al., 2001; Meire et al., 2005; Kergomard 2004) and economical (Meilliez 1998-c;Letombe et Zuindeau 2004) consequences in the coal basin or the territorial gouvernance of water territories (Kergomard 2004). This is a first step but there's a crucial need for a transboundary (i.e. France, Belgium and The Netherlands) and multidisciplinary (i.e. ecologists, economists, hydrologist, geographers …) permanent scientific cooperation to monitor the Scheldt environmental status and to analyze the hydrosystem complexity at basin scale. This cannot be realised without pointing out the gaps of knowledge that still remain in the watersystem processes and the complex Man-Nature interactions in the Scheldt watershed. For the ground and water levels issues one of the main tasks is to collect, organize, and develop a specific scientific knowledge and databases in order to analyse the space-time variations. To succeed in this task a monitoring program has to be implemented. The methodology should be based both on remote sensing technology (for a spatialy distributed analysis at basin scale) and on a qualitative and quantitative monitoring (for a process analysis at stational scale). The results should feed an operational GIS built to provide scenario for a territorial decision-making within EC water directive objectives. It could also fits a more prospective analysis (middle and long term) in this transboundary context.

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THE ARCHITECTURE OF A DECISION SUPPORT SYSTEM (DSS) FOR GROUNDWATER QUALITY PRESERVATION IN TERCEIRA ISLAND (AZORES)

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Abstract. Pollution, increase of water demand, and Global Climatic Changes are the main threats that affect water resources and that make crucial the development of effective planning and management strategies of water resources. Agriculture is one of the most important human activity with a major impact on water resources as it requires huge amounts of water and fertilizers. In the Azores Islands, the impacts of agriculture and dairy farming on groundwater quality are deeply felt, as well as the need of effective tools to support decisions. In this work, the architecture of a Decision Support System (DSS) for integrated water management in Terceira Island (Azores) is presented. Great attention is given to the description of the case study and to the different types of models that are necessary. The DSS includes chemical/physical/ecological models and decision models, in order to propose strategies based on optimisation criteria. In particular, four sub-models (hydraulic, chemical, agricultural, and dairy farming) are considered, and decision variables, objectives, and constraints of the decision problem are identified.

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1. Introduction

Water resources are essential for human life and activities and their preservation is a crucial task. Specifically, it is important to define planning and management strategies able to satisfy water needs, taking into account environmental, ecological, economic, social and legislative issues.

Water management includes a wide set of correlated problems that should be taken into account as they strictly interact with water demand, water availability, and water quality. The accurate definition of water quality indexes has been the goal of several regulations (such as in the 2000/60/EC directive). Several models based on optimization techniques have been developed to determine suitable trade-offs between the conflicting objectives of sustaining human activities (e.g. agricultural) and preserving natural resources and the environment (e.g. Southgate, 1990; Jones and O'Neill, 1992). It should be reminded, however, that such decision processes, as other decision processes dealing with the management of environmental systems, are generally quite complex (Wierzbicki and Makowski, 2000), and require a non linear multiobjective setting, a deep analysis of the territory, and a careful investigation of the preference structure of the various decision makers that are involved in the decision process (Soncini-Sessa et al., 2003).

There is the need of an integrated approach able to take into account all objectives of the decision problem, supported by simulation models to describe the water system under different viewpoints (hydraulic, chemical, biologic, hydrologic, etc.). An effective approach to support the so-called Integrated Water Management (IWM) problem is the one based on the development and application of Decision Support Systems (DSSs), integrating all these aspects (Lombardo et al., 2003; Denzer, 2005; Bazzani, 2005).

In literature, Decision Support Systems (DSSs) for water resources management are widely recognised as the primary tools to assist decision makers in their judgment (Nalbantis et al., 2002; Lombardo et al., 2003; Minciardi et al., 2004, Dentinho et al., 2006). They are generally based on the integration of decision models (characterized by the definition of decision variables, objectives and constraints), simulation models (to describe the water system under different viewpoints, and Geographic Information Systems (GIS) tools (to view data and results on a map).

The exigency to find appropriate instruments to support decisions in IWM is particularly felt in the Azores islands, where the increasing of tourism and the intensive activity of dairy farming have taken to rising water demands and water quality depletion.

The Azores are a group of nine volcanic islands situated in the confluence of the African, American and European tectonic plates, over the Atlantic Ocean Rift. With a population of 250 thousand inhabitants, the larger island (São Miguel), has an area of approximately 750 square km, and a population of 125 thousand inhabitants, and the smallest (Corvo), only 17 square km, and 400 inhabitants. Of the nine islands, São Miguel, and Terceira (with its 55 thousand inhabitants), are the most important, having more than 70% of the total population of the Azores, and being responsible by almost 80%, of all the economic income of the islands.

In geological terms, the islands are fairly recent, with volcanic activity in most of the islands, being some hot springs, and emissions of gases the most visible demonstrations. From the hydrological point of view, the islands are conditioned by their physiographic and climatic nature. Since the most of the basins discharge into the ocean, there isn't a very developed superficial network of streams and lagoons, and most of these are not of a permanent nature. Thus, most of the water resources of these islands are of underground nature, and conditioned by the complex geology.

Considering the nature of the water resources that these islands possess, there are mainly springs that result from the intersection of suspended aquifers with the surface, and wells that are used to complement the insufficient water supplied by the springs. The water treatment systems are, in most cases , rudimentary and solely composed by a chlorination facility that provides the disinfection of the water supply.

Nowadays, the main agricultural production of these islands is dairy farming, which is more intense in the islands of São Miguel and Terceira.

The produced milk is used to make dairy products, such has butter, cheese, powder milk, or it is simply pasteurized and sold. The animals are bred on pastures. They are moved along the year from one place to another, depending on the climatic circumstances during the year. These are fed with grass and corn leaves, in the natural form, or as ensilage. As a matter of fact, in the Azores Islands, the milk production is growing as it is evident in Figure 1.

The practice of dairy farming is well connected with changes in the land use of these islands, as the feeding of the animals is mainly made with forage and corn. During the winter, when there is enough grass in the fields, the animals are kept outdoor, normally at low altitudes, feeding on the available grass available, with supplements of rations to increase productivity of milk. In the summer the animals are moved to higher locations, and the fields can be used to grow corn and grass.

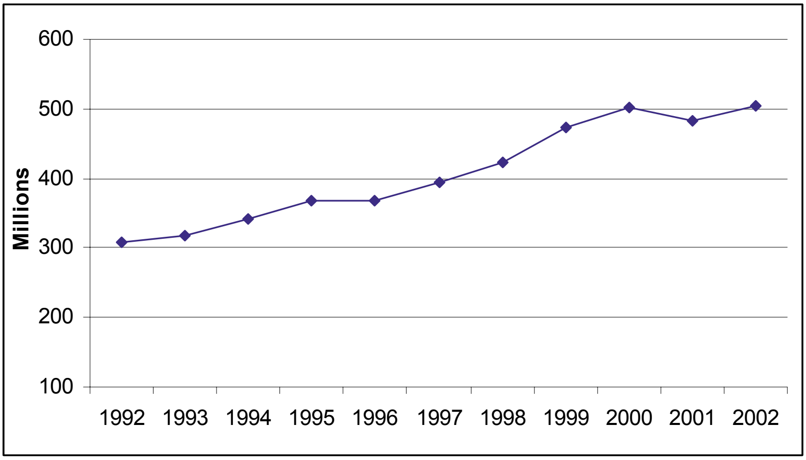

Figure 1. Evolution of the milk production (in millions of liters) in Azores (source SREA, 2004)

To guarantee the productivity of the fields, there is a substantial use of fertilizers, and, in the most part, this is done on empirical knowledge of farmers. Also the high density in which the animals occur should be taken into account for the discharge of large amounts of nitrogen in a small area, due to the direct input of animal wastes (Hubbard et al., 2004). The intensification of the agricultural practices leads to a decrease of groundwater quality, especially with the increase of the high concentration of nitrogen in drinking water in its NO_3 form. This compound causes methemoglobinemia (blue baby disease), whereas other forms of N (primarily nitrite, NO_2) are considered to be potentially carcinogenic (Hubbard et al., 2004).

Finally, it has to be mentioned that in the last years, a new source of income for the islands has gained strength: tourism. This has led to an increasing demand of natural resources, as well as a particular attention to the environment conservation for tourist attraction.

The aim of this work is to describe water management problems of Angra do Heroísmo (Terceira Island, Azores) and to define the modelling needs in order to build a Decision Support System for this case study. The main objective is to find appropriate solutions for integrating simulation and optimisation tools, which can support the different decision makers, and not the one of building accurate simulation tools.

The Decision Support System is characterized by three main modules: a Geographic Information module in which all maps regarding the case study area are stored, a simulation module in which the chemical/physical/ecological models are formalized, and an optimisation module in which the decisional problem is formalized.

In the following sections, after a description of the case study, the models used to describe the environmental system are described together with the decision variables necessary to build the optimisation problem.

2. The Case Study: Terceira Island

The main municipality of Terceira Island is Angra do Heroísmo (see Figure 2), that has a population of 35 thousand inhabitants. The main economic activity is dairy farming, and, in the last years, the tourism industry. The water supply system is managed by a municipal company (Serviços Municipalizados do Concelho de Angra do Heroísmo), that is responsible for all the public water supply, wastewater systems, and garbage disposal services.

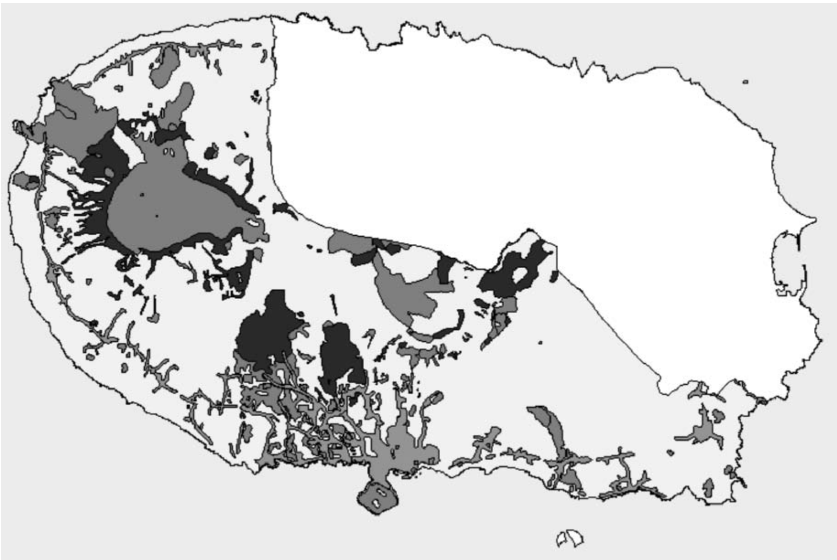

Figure 2. Municipality of Angra do Heroísmo

The water network system reaching the entire municipality is composed by springs, some wells, reservoirs, and all the pipes that are on the public ground. In the last years, the development of the island, the agricultural and industrial activities have given rise to an increase of the water demand (see Figure 3). The water services have tried to answer with an increase of the water captation systems at the springs and digging wells.

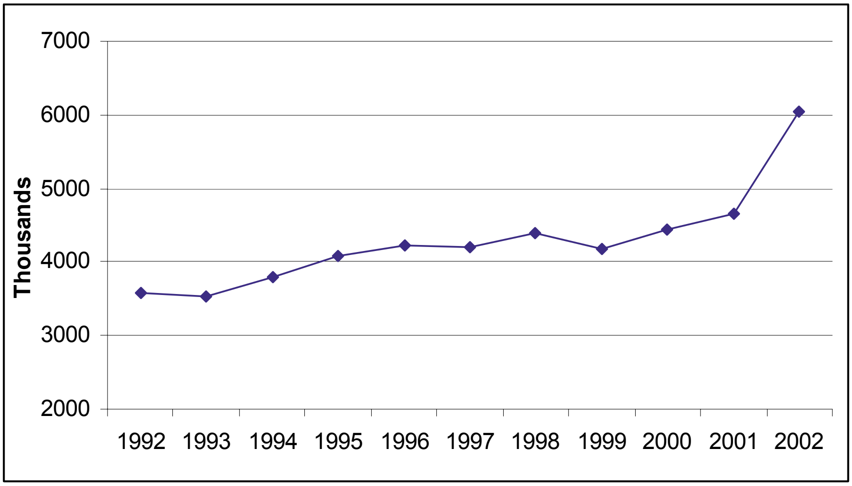

Figure 3. Evolution of the water consumption in thousands of liters in Terceira island (source SREA, 2004)

Terceira island, due to its volcanic nature, presents a complex geological structure. From east to west, it includes four central polygenetic volcanoes with calderas (Serra do Cume, Guilherme Moniz, Pico Alto e Santa Bárbara) and in the center and south-eastern parts of the island a basaltic fissured zone (Montesinos et al., 2003). This structure reflects on the hydrology of the island, making it a very complex issue. Then, the island is characterized by the existence of a basal aquifer, that holds most of the island water reserves in a state of equilibrium with the ocean salt water, and a high fissured geology.

Some works have been developed in attempt to characterize more thoroughly the island hydrology, like Rodrigues (2002). Still many questions remain unanswered, in association with the problem of the frequent seismic activity which often modifies the same structure by creating fissures in the various geological structures.

For the aim of this work, it has been chosen to use the main hydrological units defined in *Plano Regional da Água* (Direcção Regional de Ordenamento do Território e dos Recursos Hídricos & Instituto da Água, 2001), as a base to the general characterization of the island hydrology.

The surface water is not considered, due to the non-permanent nature of the watercourses, flowing only in the times of great precipitation intensity. This non permanent nature of the water courses is due to the small catchments areas of the various basins, and to the high soil infiltration rate, as Fontes et al. (2004) report.

The main problem of the island is the preservation of water quality and the respect of the Portuguese and the European standards. In fact, the development of the agricultural activity (that is however essential for the island economy), the use of increasing amounts of fertilizers in order to increase the fields productivity, the dairy farming practices, and the increasing water demands are causing a depletion of groundwater quality.

Thus, the main problems that should be faced, with the help of a Decision Support System, regard both water supply and water quality, paying attention to the needs of the farmers and to the increase of activities during summer. On the water quality point of view, water from the wells and springs is not of good quality.

3. The System Description: The Chemical, Physical, and Ecological Models

Different types of models have been considered: the hydraulic model, the chemical model, the agricultural model, and the dairy farming model.

Figure 4 represents the interactions among these four subsystems. Hydrological data are used to build the hydraulic model that influences the transport and the dilution of pollutants in the groundwater.

The chemical model is influenced by two main contributions of pollutants: the amount of fertilizers used for crop yield production, and the waste of animals grazing in the area.

The yield production (that is calculated by the agricultural model) is function of the nutrient input (both fertilizers and waste from animals), of the soil characteristics, and of the area climatic conditions.

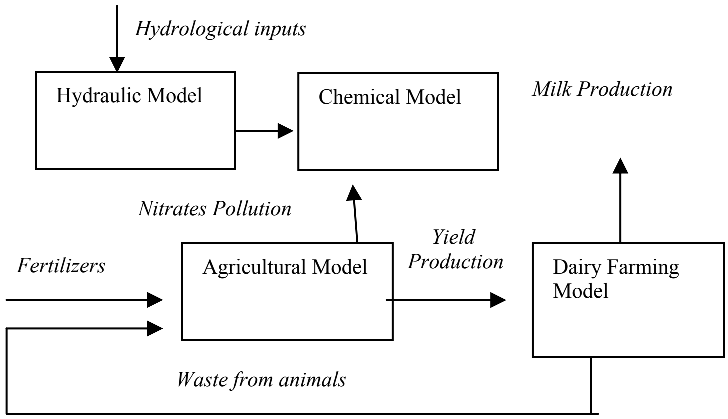

Figure 4. Evolution of the water consumption in Terceira island (source SREA, 2004)

Finally, the dairy farming model (determining the amount of milk produced and the number of cows in the territory) influences the chemical model.

3.1. THE GROUNDWATER MODEL: THE HYDRAULIC MODEL AND THE CHEMICAL MODEL

The hydraulic and chemical models are formalized as multicell models (Minciardi et al., 2004). For this reason, the case study area is divided into tree major cells, with two sub cells each. The six cells are characterized by homogeneous characteristics and have at least an outgoing source of water, well or spring. For the location and delimitation of the cells, it was taken into consideration the major hydrological framework defined in *Plano Regional da Água* (Direcção Regional de Ordenamento do Território e dos Recursos Hídricos & Instituto da Água, 2001), and the location of the different springs and wells, forming in this manner homogenous hydrological areas. Figure 5 highlights the six cells considered in this work. It is important to note that the springs, because they form a closely associated group in each cells, will be considered as a single output unit for each sub cell.

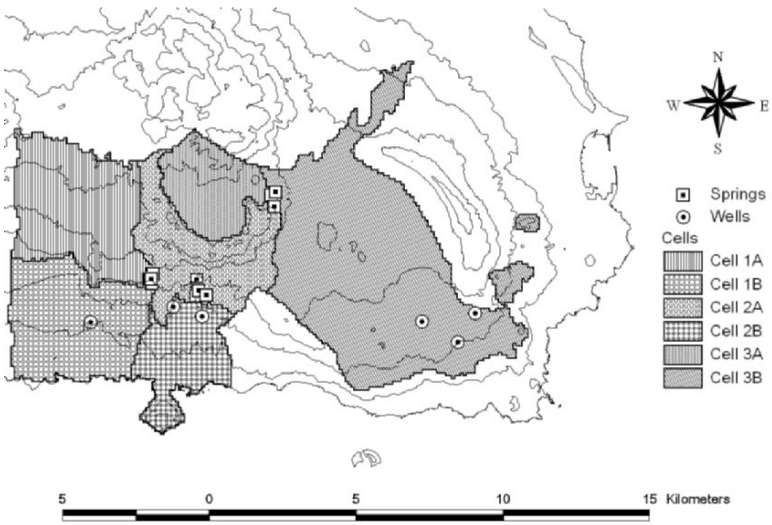

Figure 5. The cells of the study area

The hydraulic model has been built considering the water balance of every cell and the leakage among cells that is governed by the Darcy law. Figure 6 shows the positive and negative contributions to the water balance of every cell.

The water balance of the generic cell *i* is given by the sum of the different inputs, minus the sum of the outputs. The inputs are the precipitation (P^t_i) and the fog interception (Fog^t_i), in cell *i* (m^3). The outputs are the evapotranspiration (E^t_i), the flow of the springs (Q^t_i), the pumped water of the wells (W^t_i), and the flow of water by percolation at the bottom of the aquifer (R^t_i), all in m^3. There is also the need to consider the flow of water to (and from) the adjacent cells (L^t_{ij}), which assumes positive or negative values depending on the difference between the hydraulic heads in two confining cells.

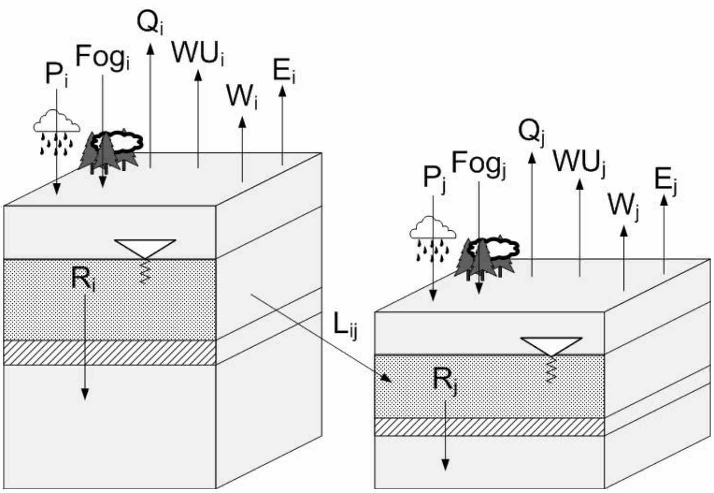

Figure 6. Hydraulic model inputs and outputs

The system inputs depend on the climatic conditions, precipitation (see Figure 7) and evatranspiration (calculated by the Thorntwaite Method). They can be estimated using the CIELO model (Azevedo et al., 1999), which provided data at one hectare scale, allowing a more accurate differentiation of the various cell and sub-cells.

The data regarding the flows from the springs, and the pumped water of the wells, were calculated by using data from the *Plano Regional da Água* (Direcção Regional de Ordenamento do Território e dos Recursos Hídricos & Instituto da Água, 2001), and data from the Angra do Heroísmo waterworks (SMAH – Serviços Municipalizados da Câmara Municipal de Angra do Heroísmo).

As regards the chemical model, nitrates are the pollutants that are taken into account (NO_3^-). The mass balance equation is almost equal to the water balance equation, with the exception that every flow is multiplied for its concentration. The other new elements are the reaction and adsorption terms for the nitrates and the amount of nitrogen, due to fertilizers and animals' waste, that percolates

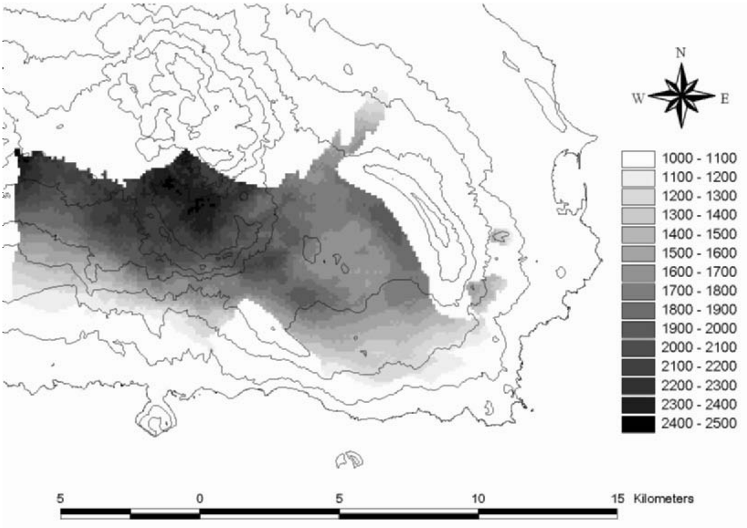

Figure 7. Annual precipitation in the study, calculate with the CIELO model (Azevedo *et al.*, 1999)

in the groundwater. The input of animals' waste depends on the density of animals present in the various cells in a specific time period and on the area dedicated to a specific land use (corn, pasture, grass) in every cell.

3.2. THE AGRICULTURAL MODEL

Three major types of yield (and food sources for the dairy animals) are considered: maize silage, forage, and pasture. The yield produced by crop *c* in cell *i* at time *t* is a function of the amount of fertilizer used for the specific crop (Reid, 2002). Specifically, it is necessary to define, for every crop, the equation that relates the input of fertilizers and the crop growth. The crop growth equations are fitted with data available for the case study. Moreover, there is also the need to consider the possible scaled harvest yield, because not all of the production of crop *c* in cell *i*, at time *t* has a possible utilization for the animals. Finally, it is necessary to calculate the useful quantity of crop *c*, in cell *i*, utilized by the animals, that results from the harvested yield versus the dry matter content of the crop versus the area of the crop *c* in cell *i* at time *t*.

3.3. THE DAIRY FARMING MODEL

The dairy farming model consists in the definition of the feeding needs of the animals and the milk production. Having defined a typical farm, with a fixed age, status and weight of the animals, using the method of the Metabolized

Energy (ME) (Agnew & Newbold, 2002), it is possible to calculate the nutritional needs of the defined farm.

Using the defined values Dry Matter (DM) and Metabolized Energy (ME) for the different feeds, like those in Table 1, it is possible to know the energetic value of a certain amount of a specific kind of feed. In this way, the agricultural model and the dairy farming model are linked.

The required ME, that should be satisfied by the different kinds of food, is divided in different components: the required metabolized energy for the maintenance of the animals, for growth, and for the milk production.

As a consequence, the milk production is function of the Metabolized Energy (and of course of the provided food), of the density of animals in the cells, and of the land use in every cell.

TABLE 1. Values of Dry Matter (DM) and Metabolized Energy (ME) for different times of feeds for dairy cows (adapted from Garcia, 2001).

Year	**Feed**	**Season**	**DM (%)**	**ME (MJ/kgDM)**
1	Pasture	Winter	–	–
		Spring	22.8	11.8
		Summer	21.8	11.1
		Autumn	15.4	11.8
	Maize silage	–	29.0	10.5
	Grass silage	–	25.0	10.4
2	Pasture	Winter	18.6	12.2
		Spring	18.1	11.7
		Summer	21.9	10.1
		Autumn	19.9	10.2
	Maize silage	–	30.0	10.8
	Grass silage	–	27.3	10.6
3	Pasture	Winter	16.6	11.2
		Spring	17.9	11.7
		Summer	32.1	9.0
		Autumn	21.2	11.0
	Maize silage	–	31.5	10.4
	Grass silage	–	25.1	11.3

4. The Optimization Module

The formalization of the decision model, describing the optimization problem, is characterized by the mathematical definition of state and control variables, objectives, and constraints. State variables represent the state of the system, while control variables represent the entities on which it is possible to operate when planning or managing. For the specific case study, considering $i=1,...,I$ cells, $c=1....C$ crop types, $t=1,...,T$ time intervals, the state and output variables are:

- H_i^t : hydraulic head in cell *i* at time *t*
- C_i^t : concentration of nitrates in cell *i* at time *t*
- $Y_{i,c}^t$: yield produced in cell *i* for crop *c* at time *t*
- $Milk_i^t$: milk produced in cell *i* at time *t*
- M_c^t : quantity of food *c* stored in the magazine at time *t*.

Instead, the control variables are:

- $FOOD_{i,c}^t$: food of typology *c* provided to animals present in cell *i* at time *t*
- $D_{c,i}^t$ density of animals at time *t* in crop area *c* in cell *i*
- $A_{c,i}^t$ area dedicated to land use *c* in cell *i* at time *t*
- Q_i^t water pumped from cell *i* at time *t*

The optimization objective is the maximization of total milk production. The other issues of the problem can be considered through the formulation of specific constraints. In particular, the constraints included in the mathematical formalization regard specific limitations (concentration limits imposed by regulation, technological requirements, environmental limitations, etc.). Different classes of constraints are formalized. Water quality preservation can be taken into account by posing a limit on fertilizers' quantity, and over pollutant concentration, while water demand constraints fix a minimum water demand for each time interval. Then, limits on the animals density on the territory are considered. Finally, different constraints for the land use have been formalized. First of all, the total area dedicated to crops that should not exceed a given value. Then, it is necessary to consider that there are some areas where a specific crop can not be cultivated due to altitude. Other constraints arise from the consideration that crops can be cultivated only in specific time periods during the year.

5. Conclusions

Water resources planning and management is a complex task because it is necessary to take into account different aspects (environmental, social, legislative, economic) and different targets. The aim of this work is to present the architecture of a Decision Support System for water resources planning in Terceira Island (Azores), with specific attention to the description of the case study and of the models and decision variables necessary to build the DSS.

The main problems that should be faced with the help of a DSS regard both water supply and water quality, paying attention to the farmers needs. Specifically, the water supply problem results from the increase of the water demand, in the summer (due to the decrease of the water flow from the springs, and the increase of the consumption by the tourist activities). On the water quality point of view, water from the wells and springs is not of good quality.

The DSS necessitates of four sub-models for the representation of the system (the hydraulic model, the chemical model, the agricultural model, and the dairy farming model), a decision model, and a GIS platform in order to represent data and results on the map.

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GREECE: ECOSYSTEM BASED IWM PLANS IN THE FRAMEWORK OF WFD IMPLEMENTATION: THE "STRYMON" PILOT PROJECT

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Abstract. Greece exhibits a complicated and of extreme beauty natural environment consisting of a "mosaic" of interrelated physiographic and climatic types which is reflected in the presence of a great variety of ecosystems with highly diverse flora and fauna. Within the national territory are situated about 400 wetlands. The Water Framework Directive (WFD), being now in an implementation process, requires that the functioning of wetland ecosystems should be understood when managing ecosystems in the framework of Integrated Water Management (IWM). To this respect, plans are formulated and their very aim is the application of IWM models in the study areas, which will constitute the main administrative tools for the formation and further periodical update of the Management Plans per River Basin. The STRYMON River Project, in Northern Greece, is a pilot project facilitating the formulation and optimal implementation of the above plans. The overall objective is to promote the sustainable management of surface and ground water bodies. Four Natura 2000 sites, including Lake Kerkini are included in the Strymon River's catchment area. This pilot project involves four distinctive sets of activities: a) Planning for sustainable tourism, b) creation of a database for matters of nature, c) public awareness activities and d) elaboration of a monitoring system in the Strymon delta and the coastal zone of Strymonikos Gulf. The main characteristics and the expected results of the Strymon project are presented in this paper.

Keywords: integrated water management, wetland ecosystems protection, sustainable river management

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1. The Natural Environment of Greece: An Outline

From a geographical viewpoint, Greece belongs to South-eastern Europe and to the Eastern Mediterranean region. It is the crossroad of three continents, namely, Europe, Asia, and Africa. The geomorphology of Greece is diverse since it is primarily a mountainous country, with seventy per cent of its territory covered by mountains but it has a very long coastline, with a plethora of peninsulas and islands. The country's Mediterranean climate is markedly influenced by the combination of geography and geomorphology, with rainy winters and dry summers. However, one encounters many specific climatic types ranging from the semi-arid and desert-like type of South-eastern Crete to the cold wet continental type of the Rodopi mountain range in the north, on the Greek-Bulgarian border. The abiotic diversity, most notably the "mosaic" of micro-climatic types, is reflected in the presence of a highly diverse flora and fauna and a great variety of ecosystems.

The flora of Greece is composed of Mediterranean, Central European and Irano-caspian elements. Over 6,000 plant species have been recorded so far. There is a large number of endemic species relative to the size of Greece, due to the isolation of the numerous mountains and islands. In Europe, a higher number of species is found only in the Iberian Peninsula, where the flora also includes species of the Atlantic zone.

The fauna consists of a rich mixture of European, Asian and African species, including a considerable number which are endemic. The freshwater fish fauna is one of the richest in Europe: 107 species, of which 37 are endemic, in the standing and running water systems of the country. Moreover, 40 endemic subspecies have been recorded. Greece is very important ornithologically since 407 bird species have been recorded, of which 240 nest in Greece (59% of the total). Some species (e.g. Pelecanus crispus) nest only in Greece of all EU countries. The mammals of Greece include 116 species, of which 57 belong to IUCN endangered species categories. The ecosystems range from the semi-desert like ones of South-eastern Crete to the cold climate mountain forests of birch, Scotch pine, and spruce. This variety often appears within small areas. For example, in a 150 km transect from the coasts of the North Aegean to the top of the Rodopi mountain one encounters ecosystems of Mediterranean, Central European and Scandinavian type.

2. Conservation and Management of Ecologically Important Areas

Twenty five per cent of Greek territory is today characterised as forest land and is subject to the protection of the forest code. Sixty five per cent of forest land is owned by the State. Since 1937, Greece has started to identify natural areas of specific ecological importance (forests, wetlands etc.) and place them under special protection. There are seven categories of protected areas: (a) National Parks (11): they cover 65,000 hectares. The most renowned is the one on Mount Olympus. b) Aesthetic Forests (19): about 33,000 hectares are in this category due to their landscape aesthetics and ecological importance. (c) Natural Monuments (51): small areas hosting single trees, groups of trees, small forested sites, geological formations, or even very small islands, of specific ecological, historical or cultural interest. (d) Wetlands: the inventory of Greek wetlands published by EKBY in 1994 lists 378 sites and complexes of sites covering about 210,000 hectares. According to the Ramsar Convention, ratified by the Greek Parliament in 1974, all these wetlands should be preserved and protected. However, 11 sites or complexes of sites are recognised as Wetlands of International Importance and enjoy special protection status. Lake Mikri Prespa is a Ramsar site and a part of the Prespa National Park. (e) Controlled hunting areas (7): these areas have sizes ranging from 500 to 5,000 hectares. Hunting is allowed only to those holding special permits and under severe restrictions. (f) Game refuges: there are numerous areas all over Greece where hunting is altogether forbidden to ensure the protection and reproduction of game species. (g) National Marine Parks: this is a very recent development for Greece. So far, only one such park has been established, in the Sporades Islands, for the protection of the monk seal. (h) Special Protected Areas according to Directive 79/409/EEC: Directive 79/409/EEC on the Conservation of Wild Birds was ratified in Greece by the Joint Ministerial Decision of the Ministers of National Economy and of Agriculture, No. 414985/85.

The directory “Important Bird Areas (IBAs) in Europe” included 113 sites of importance in Greece. Of these 113 sites, 50 are protected under the “Special Protection Areas” (SPA) regime. In addition, Council Directive 92/43/EEC, also known as the “Habitats Directive”, is a recent legislative instrument in the field of nature conservation. Following on from the Directive on the Conservation of Wild Birds, it establishes a common framework for the conservation of natural habitats and of wild fauna and flora species and provides for the creation of a network of Special Areas of Conservation (SAC) called “Natura 2000” to “maintain or restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest”.

The legal framework pertaining to the conservation and management of the above mentioned protected areas has not so far been enforced effectively. However, the efforts towards improving the laws and enforcing them are gradually being put at higher priority levels both by the government and by society.

3. Management of Wetlands in Accordance with the WFD

As it is known, *wetlands* are areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. A cardinal characteristic of the transitional zone between the permanently flooded and the strictly terrestrial areas is the presence of hydromorphic soils and hydrophilic vegetation. Greece has today about 400 large and small wetlands. Several of them are composite and form wetland mosaics or complexes.

The most common wetland types in Greece are: rivers, estuaries, deltas, lagoons, shallow lakes, shallow marine formations, marshes. Their total area is still quite large (210,000 ha) in spite of the heavy losses that occurred during the last two generations.

In 1992 the Rio Convention and the EU Directive 92/43 were designed to confront the threat of extinction of many species and the deterioration of the worlds' habitats. The EU Habitats Directive 92/43 was incorporated into Greece's national legislation by the Joint Ministerial Decision 33318/3028/1998. The main aim of the Directive is to promote the maintenance or restoration of biodiversity, taking account of economic, social, cultural and regional requirements. The natural habitat types and the species are listed in Annexes I and II of the Directive. The backbone for the conservation and protection of the natural environment is the creation of a European ecological network of protected sites named NATURA 2000. The network will be under a special management committee consisting of representatives of the member states.

To achieve the goal for the identification and evaluation of biodiversity, the Directive was implemented in Greece in 1994 by a national project titled "Inventory, Identification, Evaluation and Mapping of the Habitat types and Flora and Fauna species in Greece". The creation of the NATURA 2000 network, to which Greece is committed, will assist in the protection of endangered species and their habitats by ensuring their restoration and maintenance at a favourable conservation status (Mihalatou, E., 2001).

Within the Greek territory 268 sites are existing, forming the country's National List, and 52 Special Protected Areas (SPAs) are included according to the Directive 79/409/EEC. The Directive imposes on the State the responsibility for making an appropriate assessment of any plan and/or programme likely to cause a significant effect on the conservation objectives of the site which has or will be designated in future. To accomplish this goal the Greek State is empowered to implement all necessary protection and management measures in regard to the conservation objectives pursued. Guidelines for this particular task have been established few years ago (Kakouros, P., Tsiaoussi, V. and Hadjicharalambous H., 2004).

The Water Framework Directive (WFD), currently being under implementation within the EU countries, requires that the functioning of wetland ecosystems should be understood when managing ecosystems in the framework of Integrated Water resources Management (IWM).

The EVALUWET consortium aims at developing a decision-making system that will enable evaluation of the European wetland resources in line with the requirements of the WFD and the operational conditions of relevant agencies. It addresses problems of linkage between natural science and socio-economic evaluation systems and develops a seamless system, which enables complete wetland evaluation to assist sustainable management.

The objectives of the project are being achieved through the following key issues:

- Harmonisation of European user agency wetland policy implementation.
- Development of a Wetland Evaluation Decision Support System (WEDSS) and the integration of the wetland evaluation tools. The WEDSS will directly support environmental agency decision-making in the context of the WFD.
- Development of a catchment scale wetland functional evaluation methodology and tools. It will constitute a module in the WEDSS and its operational criteria will be established from user consultation.
- Incorporation of economic valuation, stakeholder analysis and multi-criteria decision making methods into the WEDSS.
- The project partners are: RHIER, UK (Project Leader), UEA-CSERGE, UK, IVM/VU, Netherlands, Bucharest University, Romania, University of Utrecht, Netherlands, UFZ, Germany, ARUM, Germany, SLU, Sweden, MDC, Sweden, SJV.V, Sweden, ECOBIO, France, ILESAS, Slovakia, EKBY, Greece.

There is presently a trend in Greek society towards the recognition of the immense importance of the multiple values of the country’s wetland resources (WWF/EC, 2000-’01). This trend, however, is not so far attained the necessary strength to arrest wetland degradation which is caused by unsustainable activities in the wetlands and their watersheds.

The road to the sustainable management of wetland and terrestrial ecosystems will therefore be long and hard. The outlook is optimistic provided that conservation efforts are coordinated and that human communities living close to natural ecosystems are more actively involved in conservation and management (Zalidis, G.C., Papadimos, D. and Katsavouni, S., 2002).

4. IWM Plans in Greece, Years: 2003-2007

IWM plans are structured and will be running within the period 2003-2008 in Greece and in particular in the northern part of the country, where the majority of protected wetlands is situated (Hellenic Ministry for the Environment, Physical Planning and Public Works, 2002-2005). The very aim of the plans is the application of models for the management of water resources of the particular study areas which will constitute the main administrative tool for the formation and further periodical update of the Management Plans of Water Resources per River Basin in accordance with the WFD.

The plans are materialised through the following actions:

1. Recording of characteristics of the Water Districts in the region of study, with positioning maps and limits of aquatic bodies (surface and underground) and ecosystems, characterized in terms of type and situation according to the WFD.
2. Recording of pressures and impacts (quantitative and qualitative) to the surface and underground waters due to the human activity.
3. Recognition and depiction of protected areas in maps.
4. Digital map presentation of the environment monitoring network and its results.
5. Economic analysis on water uses (as article 5 and Annex III of the WFD).
6. Development and calibration of water basin management models (one for Water District).
7. Proposals for measures, cost estimate and computation of their benefits (economic and environmental) with the application of the integrated river basin management model (RBMM).
8. Education of competent personnel, proposals for the optimal exploitation of the RBMM, communication of Project and its conclusions to the public (article 14 of the WFD). The technical approach is based on the installation of three compatible and mutually interconnected software components that all together fulfil the requirements in TOR: I) The MIKE INFO GIS-based Water Resources information system for storage of all spatial and time series information, relevant info for the resource assessment as well as on the use and demand of the water. II) The MIKE-SHE integrated hydrological/ hydrogeological modelling system. III) The MIKE BASIN operational water management model.

Strymon River Project, in Northern Greece, is a pilot project that reflects the philosophy and methodology of the above mentioned Plans, in the framework of facilitating the implementation of WFD in Greece.

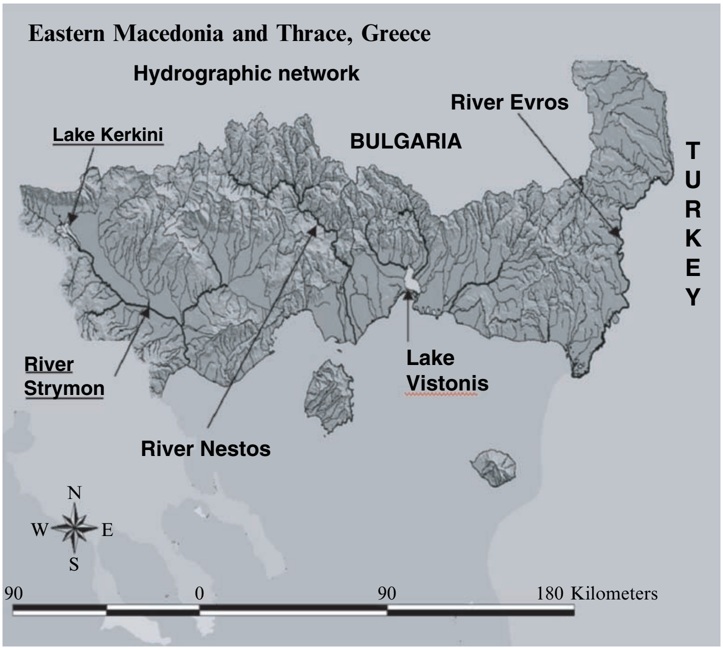

Figure 1. The natural hydrographic network of Eastern Macedonia and Thrace region, Northern Greece (courtesy of Prof. M. Mimikou, NTUA, Greece, with modifications)

5. Strymon River Project

5.1. STRYMON RIVER BASIN

The Greek part of Strymon River basin is located at the western border area of Eastern Macedonia and Thrace region, Northern Greece (figure 1) and covers an area of 6,472 km2. Strymon River and Lake Kerkini are the two main surface water bodies in this part of the river basin, as it is evident in fig. 2, which in turn contribute to the Serres plain with ground water. Lake Kerkini was constructed during 1933-36 mainly for protection against floods caused by Strymon River. Soon after it was used as a reservoir for irrigation water.

Agricultural activities, which constitute the main threat to surface waters and groundwater in the basin, take place in its lower part (elevation less than +100 m), which covers an area of 100,000 ha. This area is irrigated by a dense irrigation network. The Land Reclamation Service of Serres (DEB-S) is responsible for the water resources management in the agricultural area through its administrative and technical supervision of the General Land Reclamation

Agency (G.L.R.A.) and of the 10 Local Land Reclamation Agencies (L.L.R.A.). These agencies manage the land reclamation works and the distribution of irrigation water.

5.2. LAKE KERKINI

Lake Kerkini is wetland protected through national, international, and European legislation. It is commonly referred to as an artificial lake that functions solely as a reservoir supplying irrigation water to the plain of Serres. The wetland and its values being promoted today are seen as the result of the engineering works, which have been carried out since 1937, to build the embankments and the Strymon dam. The area is a paradise for birds and people since there exists an enormous wealth of plant and animal life that led to the lake being designated as a wetland of international importance. Even today it has one of the highest levels of biological diversity among Greek wetlands.

The seasonal flooding, together with the silt brought down by the River Strymonas, makes this area very fertile; it is covered with lush vegetation abounding in plant species. The lakes ecosystems range from the riverine forest, the heart of the wetland, with its willows, tamarisk, alders, plane trees, ash and poplar trees that make an invaluable nesting and breeding ground for aquatic birds and also a refuge for fish, to the impressive carpet of water lilies that covers about 5 sq. km of the lake, en extraordinary extent for European conditions; from the wet meadows that provide rich feeding grounds for herons, spoonbills and glossy ibis, to the shallow waters with Salvinia and water chestnut (the latter is a globally threatened species that provides excellent nourishment for many aquatic birds); and from the sand strips formed by the river -a superb resting and breeding ground for birds- to the lake's deeper waters, teeming with fish.

This variety of habitats and flora, the abundance of food and the geographical position of Lake Kerkini have combined to make this wetland a paradise for birds, which find there the right conditions to live, breed, feed, winter or stop over on their migratory flights. Of the 244 bird species recorded in and around the lake, 70 are protected by the Directives of the European Union, among them species that are threatened in Europe or worldwide, such as the Dalmatian pelican. Other rare species are the white pelican, pygmy cormorant, night heron, spoonbill, glossy ibis, black stork and all the herons, egrets and bitterns. Most of these species breed in Lake Kerkini, building their nests in colonies in the riverine forest. It is thrilling to see such a wealth and variety of life being born in the flooded forest.

In autumn and winter, when the level of the lake is kept low to prevent flooding, the lake's area is reduced to 4,500-5,000 hectares from the 7,000 hectares it occupies in the spring. Then the bird life, while remaining diverse, changes in composition. Almost all the species that nest in Kerkini in the spring migrate south to warmer climes, and their place is taken by other birds that will winter in the area. Thousands of ducks, grebes, cormorants, pygmy cormorants and Dalmatian pelicans, as well as flamingos, flock to fish in the lake’s waters.

There have been major changes in the local environment at the area of Kerkini most of which are directly related to the building of the new dam in 1982. The most important effect was the damage to the riparian forest and the decrease of the aquatic vegetation including large beds of reeds and wet meadows due to the increase at the depth and duration of flooding. The above changes have meant large-scale damage to the birds’ and fish habitats and have resulted to the reduction of various birds and fish species’ populations.

Logging of the forest by residents of the nearby villages has also been mentioned as one of the reasons for the forest decline. Destruction of the lakeside vegetation is also attributed to buffaloes and cattle grazing uncontrollably. Grazing space next to the lake is not enough to support the needs of the big number of sheep and goats present at the Kerkini area, especially during the summer. The result is overgrazing that doesn’t allow the re-establishment of reeds and other vegetation and is considered one of the reasons for the declining vegetation. Hunters also mention that natural habitats for animals have decreased in the mountains due to intensive logging and road building activities.

5.3. MAIN ENVIRONMENTAL PROBLEMS

The main problems of the area that the project STRYMON (Halkidis, H., Papadimos D. and Lionta Chr., 2004) is aiming to solve are:

a) Water losses through the distribution system
b) The high concentration of surface waters in nutrients originating from the cultivated field
c) Degradation of the downstream agricultural soils due to their irrigation with drainage water
d) Undesirable alterations in the hydroperiod of Lake Kerkini,
e) The intrusion of the sea-water into Strymonas River during summer time irrigation period due to its low discharge.

5.4. BASIC CHARACTERISTICS OF THE PROJECT

The STRYMON project entitled “Ecosystem Based Water Resources Management to Minimize Environmental Impacts Using State of the Art Modeling Tools in Strymon Basin” (contract number LIFE03ENV/GR/000217) is a 4-years project

(2003-2007), co-funded by the European Union, the Hellenic Ministry of Agriculture, EKBY, the Directorate of Land Reclamation of Serres, the Development Agency of Serres S.A. (ANESER S.A.) and the Local Association for the Protection of Lake Kerkini (SPALK). The main characteristics of the project are sumarised in the following:

- *Beneficiary of the project:* Greek Biotope/Wetland Centre (EKBY)
- *Partners:* Prefecture of Serres- Directorate of Land Reclamation of Serres, Development Agency of Serres S.A. (ANESER S.A.), Local Association for the Protection of Lake Kerkini (SPALK)
- *Main Objective:* The overall objective of the project is to promote the sustainable management of surface waters and groundwater in Strymon River Basin assisting the implementation of Water Frame Directive.
- *Specific objectives* are:
    a) To use State of the Art Modeling Tools and Methods for the Assessment, including spatial and temporal variations, of the impacts of agricultural activities on the status of surface waters and ground water in Strymonas basin;
    b) To use optimization methods for the elaboration of solutions taking into account the needs of the aquatic ecosystems in order to address factors that have caused the problems to be eliminated;

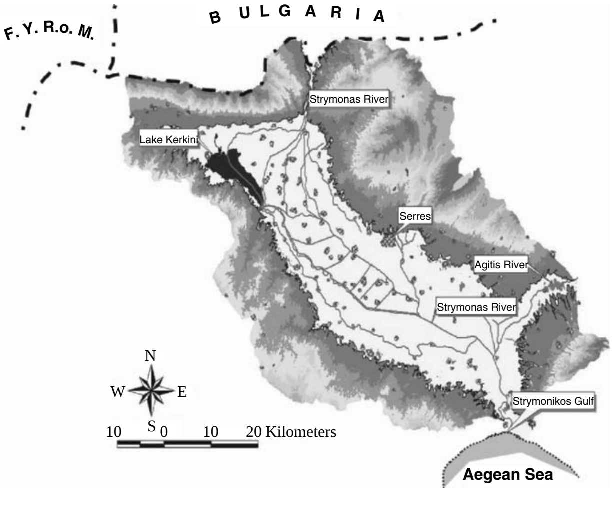

Figure 2. Strymon (Strymonas) River Basin

c) To disseminate the methodological framework as well as the results, contributing to the promotion of the sustainable water resources management at national and international level.

The project aims at the application of actions of monitoring, public awareness and promotion of sustainable development in the broader area of Strymon River. Four Natura 2000 sites, including Lake Kerkini, were chosen as central points of the catchment area.

The project involves four distinctive activities:

- Planning for sustainable tourism in the area.
- Networking of the Information Centre of Strymonikos Gulf and of Ierissos Gulf with the Information Centre of Lake Kerkini through the creation of a database for matters of nature, development projects and funding instruments.
- Support to the operation of information infrastructures and to public awareness activities: creation of a tourist map of the area, training of the personnel of the two centres and evaluation and enhancement of the existing programmes for visitors in the two centres.
- Elaboration of a monitoring plan in the Strymonas delta and the coastal zone of Strymonikos Gulf.
- *Tasks.* In order the project to meet the set up objectives a number of actions will be undertaken organized under six tasks:

  Task 1. Strymonas Basin Integrated surface waters-groundwater model.
  Action 1.1. Input data and model set up.

  Action 1.2. Model calibration, validation and impact analysis on water resources from agricultural activities.

  Task 2. Monitor the crop pattern, Water Quality and Hydrological Regime.

  Action 2.1. Satellite image analysis. Action 2.2. Application of SHYLOC. Action 2.3. Water quality and hydrological regime monitoring network.

  Task 3. Economic analysis of crop production in Strymonas Basin.

  Action 3.1. Farm management survey in Strymonas basin. Action 3.2. Technical and economic analysis of farming practices in Strymonas basin. Action 3.3. Environmental policy in Strymonas basin.

  Task 4. Water resources management planning.

  Action 4.1. Elaboration of optimum management plans in agricultural sector in Strymon basin. Action 4.2. Testing the impact of the proposed management plans on water resources and their aquatic ecosystems.

  Task 5. Management and Reporting to EC.

Action 5.1. Establishment and operation of the project management structure.
Action 5.2. Reporting to the E.U. on the technical and financial progress of the project.

Task 6. Dissemination of knowledge and public awareness

- *Innovation and Methods.* The Methodological approach to the objectives of this project and the use of State of the Art modeling tools, are the main innovations of STRYMON project. The use of State of the Art modeling tools will be engaged to the assessment (including spatial and temporal variations) of the status of surface water and groundwater in Strymon basin. Innovative methodology will be used for: a) surveying the farm management practices in the basin and b) consultation with stakeholders in preparing alternative scenarios, compatible with the agro – environmental police of EC, for the protection and management of the area's water resources.
- Expected Results:
  a) Estimation of: (i) the volume of water requirements for agriculture, (ii) the water losses in the irrigation water distribution systems and (iii) the pressures exerted on surface water bodies associated from the use of agro-chemicals.
  b) Appraisal of the cost of agricultural production associated with the use of water and agro-chemicals.
  c) Assessment of the potential effectiveness of agro-environmental measures, in reducing the use of water and agrochemicals.
  d) Preparation of alternative proposals for the sustainable management of soil and water.

6. Conclusion

Given the existing political, socio-economic, legal, administrative and technical infrastructure inefficiencies, Greece needs to put a vast amount of effort towards implementing in due time the WFD. Plans have been formulated and their materialization has started regarding WRM per river basin under the guidelines provided by the WFD.

STRYMON River project represents, along with very few similar pilot projects, the set up philosophy, methodologies and criteria put forward through the now running IWM plans. In particular, it is considered to be a promising first step put forward for competent authorities and stake holders, facilitating the proper implementation of the WFD regarding the management of river basins (including the engaged protected wetlands) in the Greek territory.

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THE ROLE OF THE HELP PROGRAMME

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Abstract. Following an overview of the IWRM concept, the UNESCO International Hydrological Programme (IHP) HELP (Hydrology for the Environment, Life and Policy) programme will be outlined which addresses issues linked with stakeholder dialogue, the science-water law and water policy interface, the identification of vulnerability of drainage basins to global change, the forest and water issues, the food and water policy issue, the need for a more integrated scientific approach and how to undertake HELP in developing countries which lack both hydrological and human technical resources infrastructure.

Keywords: Integrated water resources management, HELP, water policy issues interfaced with scientific research

1. Introduction

The Hydrology for the Environment, Life, and Policy (HELP) component of the International Hydrological Programme aims to facilitate dialogue between hydrologists, social and economic scientists, water-resources managers, water lawyers, policy experts, and river-basin stakeholder communities in setting a research agenda driven by local policy issues.

By stimulating new investment in scientific, financial and human resources in catchments and accelerating experimental hydrology to support knowledge gaps of decision makers, HELP seeks to improve benefits to society of applying Integrated Water Resources Management (IWRM).

This paper offers an overview of the IWRM process and then outlines the HELP programme's actions over the next five years. Specific attention is given to the fundamental principles of HELP and to responses via the following basin-specific activities:

P. Meire et al. (eds.), Integrated Water Management: Practical Experiences and Case Studies, 247–261.

- promoting stakeholder dialogues
- defining the interface between water policy and law with science
- identifying basins 'vulnerable' to global change
- integrating forest and water issues
- determining how HELP can address food and water policy issues
- achieving a more integrated, scientific approach
- addressing scientific questions where scientific infrastructure is lacking.

2. The Integrated Water Resources Management Process

After the International Hydrology Decade (IHD; 1965-1974) and, more especially since 1990 through key international fora, initiatives to integrate the scientific-technical aspects of water with drainage-basin management have gained momentum. Such integration connects techno-scientific issues with broader, more complex socio-environmental issues. These initiatives have gained prominence via "Integrated Water Resource Management" (IWRM). Even prior to the United Nations Conference on Environment and Development (UNCED), many within and outside the water sector began to call for more integrated approaches (e.g., the U.S. Agency for International Development's "synthesis approach" for improving water management in Asia from 1979 onwards, compiled by M.K. Lowdermilk, 1981; the "integrated river basin management" concept mentioned by Burton & Boisvert, 1991; Burton, 1995). These developments are embryonic roots of IWRM. Even earlier, outside the water sector, Stern et al. (1959) had coined the term"Integrated Pest Management (IPM)." At the same time acknowledging the relevance of environmental ecology to IPM (through the concept of "Life Systems"), L.R. Clark and P.W. Geier, 1961, concurred with this integrated approach (http://www.ipmcenters.org/).

The United Nations Conference on Water (the Mar de Plata Conference, Argentina, 1977) was a catalyst for moving toward the IWRM process. It initiated intensive debate on water just prior to the International Drinking Water Supply Sanitation Decade (1981-1990). At the same time many began recognizing that economic development at the expense of the environment, was no longer acceptable. Such shift in thinking coincided with several public campaigns within the international and national media that focused on 'failed' development projects. Bonell & Bruijnzeel (2005, eds.) offer examples of the fate of tropical forests linked with land-water management concerns.

During the 1980s, a more integrated management position began to be incorporated within international water programmes. For example, from its Third Phase onwards (1984-1989), the International Hydrological Programme (IHP) has had a water-resources-management component along with its scientific research and education mandates. For the most part, however, the activities of the management and the scientific communities have remained separate. With a few exceptions, this situation continued up to IHP-IV (1990-1995) and IHP-V (1996-2001), at both the national level within Member States and within the global programme itself.

A key problem is that there are diverse disciplines, international programmes and practical users with vested interests in the water sector. Thus, IWRM remained ambiguous until recently. Some harmonisation of what was understood by IWRM was required. To fill this need, the Global Water Partnership (GWP) published a manual on the principles of IWRM (GWP Technical Advisory Committee, 2000). In parallel, GWP established a "Toolbox on IWRM" as a repository of actual experiences. GWP defined IWRM as a process, that promotes "coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."

Thus, IWRM is a holistic approach that includes both the natural as well as the human system, in contrast to a previously more fragmented management approach. The World Water Council's (WWC; 2000, p. 57) definition of IWRM based on the GWP Framework for Action (1999) expands on this holistic view, maintaining that water must be viewed "both in its natural state and in balancing competing demands on it – agricultural, industrial, domestic, and environmental ... and across sectors. If the many crosscutting requirements are met, and if there are horizontal and vertical integration ..., a more equitable, efficient, and sustainable regime will emerge."

Despite a growing consensus that IWRM appropriately addresses the pressures and demands on limited resources, a significant proportion of the scientific community is not directly engaged in IWRM. Moreover, the diverse elements and the complex interactions within IWRM raise a fundamental question: "How does one implement IWRM within real basins across a spectrum of environmental, sociocultural and socioeconomic settings?"

Such a question confounds the traditional sectoral and discipline approach to water resources management. Further, at the macro or global scale IWRM remains mostly at the conceptual stage, although the use of Decision Support Systems (DSS) in the last decade illustrates a pioneering step to apply the concept. A complementary approach is to test the principles of IWRM initially at smaller catchment scales (say from 10 to 10^4 km^2) so that community-level stakeholders can be engaged.

A key element of IWRM is the gathering and sharing of data and information related to hydrological, environmental, economic, and social sciences. Such a process requires good cross-disciplinary communication and understanding.

Unfortunately, the ability of water researchers to communicate their results is constrained, partly due to the techno-scientific roots of hydrology. Put simply, hydrologists are not usually trained to communicate outside their discipline. Moreover, few social scientists have sufficient training in hydrology. This contrasts with other fields of natural resources management such as forestry, where, social forestry is now routinely included in university curricula (Bonell, 1999).

3. What is HELP?

The disjunction between the scientific and management sectors is a "paradigm lock." To address this lock, a group of hydrologists, water managers, and policymakers established the HELP Initiative in 1999 (HELP Task Force, 2001). The initiative has solicited participation from a global network of "Pilot basins." In each of these, the science of process (i.e., experimental) hydrology is intended to be strengthened by its linkages with multiple issues involving water law and policy tools, land-water resources management, and stakeholder needs. The HELP approach is "bottom-up," including stakeholder dialogue across "scales" from communities to basins institutions and, ultimately, to national-government levels through co-operation with relevant ministerial departments.

From the outset, in response to IWRM, the formation of interdisciplinary teams of scientists, managers and policymakers demands improved crossdisciplinary communication. Similarly, local cultural knowledge and community customs of water management should be considered. An iterative process then follows of assembling existing data and information, debating issues, and defining knowledge gaps requiring a scientific response. Such a process requires interactive meetings between stakeholders and scientists to formulate basin implementation research strategies. A starting point is for stakeholders to prioritize water issues. Nongovernmental organizations (NGOs) can serve as useful institutions for distilling stakeholder positions. In this process, *all* relevant data and information need to be assembled and synthesized to better inform stakeholders. Synthesis also will identify knowledge gaps that require responses from the research community.

The first step is the "Assessment Stage" of HELP, which synthesises existing knowledge, integrates such information across disciplines as part of IWRM, and provides two main types of outputs:

- simulation of future change scenarios (e.g., land-use, demography, or socio-economics) in the water cycle and supply/demand for different future catchment states, as well as checking model predictions based on known changes in the catchment environmental-social status.

- definition of “gaps” in scientific knowledge (e.g., process hydrology understanding) that require the development of a technical implementation strategy by hydrologists in collaboration with basin stakeholders and managers. Such steps are taken to support already-defined land-water management and policy issues.

The outputs from the Assessment Stage answer a common criticism from policy makers, especially at the national-government level, that scientists do not share knowledge with users. Integration of knowledge across disciplines provides a product for improving IWRM as well as for informing the public. This can be achieved by simulating alternative management decisions (i.e., via DSS) linked with ecohydrology and socio-economic sustainability.

After establishing an agenda for scientific research and creating a science plan, HELP advances to a Research Stage This second stage requires continued dialogue with land-water managers and policymakers to ensure that research results are used to update management and policy tools. The manager’s role is critical since basin managers are at the fulcrum of HELP. To be effective, managers must have a thorough appreciation of scientific research and its role in enhancing management and policy. The promotion of a “bottom-up” approach within the network of HELP basins and close linkages between those basins, allows sharing and exchange of information on IWRM across a spectrum of environmental and sociocultural/socioeconomic conditions. Such steps move beyond the macroscale and address the intricacies and complexities of IWRM down to basins at the mesoscale (~10 000 km^2) and even to communities at the microscale (~10 km^2).

3.1. THE KALMAR SYMPOSIUM

In August 2002, a major Symposium brought together 23 of the 25 HELP basins of the Pilot phase which was held in Kalmar, Sweden. Taking into account experiences of implementing HELP in selected basins in plenary and working groups, the Kalmar Symposium yielded detailed recommendations within four HELP components:

- Stakeholder dialogues: steps, options, barriers, and how they can be overcome.
- Rules and roles in IWRM: institutions and instruments in policymaking and roles given to stakeholders.
- How to achieve acceptance of change and possible shortcuts to societal acceptance?
- Required scientific answers, bottlenecks and paradigm locks and research needed to overcome such locks.

These recommendations provided a basis for a call in October 2003 to extend the HELP basin network and to obtain progress updates from existing Pilot basins.

A review of the call for basin proposals by an evaluation committee resulted in a network of 67 basins in May 2004 (see HELP website, http://www.unesco.org/water/ihp/help). Thus, a key follow-on action from the Kalmar Symposium is already underway. Moreover, the collective experiences with IWRM of the expanded HELP network will form the backbone of the programme through networking, symposia, and workshops. Paralleling the network's expansion will be the gradual decentralisation of the international programme direction by relying on Regional Coordinating Units (RCUs) instead of the HELP Secretariat at UNESCO (Paris) as focal points for contact with HELP basins in their respective regions.

The above developments will permit the global Secretariat to take on a more strategic position by addressing particular issues within the HELP and IWRM frameworks. Within the next five years, the IHP and its international partners will initiate the following collaborative activities:

- address how to establish dialogues with basin stakeholders across sociocultural and socio-economic conditions
- develop lines of communication between the water-policy and law and scientific communities
- develop criteria to (a) better define basins that are 'vulnerable' to global change (measures of sensitivity to climatic variability and hydrological impacts of land-use change) and (b) technical approaches to improve understanding of the separation of climate vs. human-induced impacts on the hydrological cycle.
- enhance understanding of the impacts of forest conversion, and the reverse, the afforestation-reforestation of human-impacted landscapes on the water cycle and on stakeholders. These impacts are of particular concern in the tropical basins, notably in both high and low streamflows.
- address upstream-downstream issues within IWRM, from technical, management, and policy perspectives
- explore how use of the HELP approach can address national and transboundary
- basins policy issues connected with intra- and interbasin conflicts. Inclusion of transboundary groundwater aquifers as HELP basins is under consideration. Such aquifers will probably be part of IHP's ISARM [Internationally Shared Aquifer Resource Management] programme.

- create a framework for a more integrated science research perspective (i.e., remove disciplinary barriers) to better implement IWRM within the research phase of HELP basin activities
- address scientific gaps within the "water and food policy" issue.

The above activities conform to the key successful approaches to implement HELP, as identified at the Kalmar Symposium. Some additional comments on the planned global activities outlined above will demonstrate how HELP activities will be coordinated through other international programmes and meetings.

3.2. DIALOGUES WITH STAKEHOLDERS

It is apparent there is no single blueprint for stakeholder dialogue. The diversity of cultures, customs, land tenure, governance, socio-economies, and environments, requires assembling 'successful' as well as 'failed' experiences across the HELP network.

An initial step will be a workshop planned in 2007 on approaches to stakeholder dialogues that will elaborate the Kalmar Symposium recommendations. Using representation from several HELP basins, workshop participants will examine successes and failures of various approaches to stakeholder dialogue. The inclusion of social scientists and governance experts within the stakeholder dialogue will be essential. An expected outcome is the establishment of an expert group to guide HELP.

3.3. SEARCHING FOR THE INTERFACE BETWEEN WATER POLICY AND LAW WITH SCIENCE

The scientific and water-law communities are sectorally separate and do not typically understand each other. An intended contribution of HELP is to encourage better communication between these distinct groups. A later objective is for the water-law community to help identify gaps in the scientific agenda, and conversely, for scientific-research outputs to improve legal instruments. Fundamental questions from the scientific community to water-policy and law specialists include: What science is being used in legal instruments and conventions? What 'new' scientific knowledge should be incorporated to update water laws? And to the water lawyers: From experiences in applying legal instruments and conventions within water disputes, what are some recurring scientific-knowledge gaps that could improve conflict resolution?

Two steps are being taken to address the above issues. A textbook (*Hydrology and Water Law – Bridging the Gap,* Wallace & Wouters, 2006), featuring selected HELP basins from the Pilot phase, is in press. This book reviews the perspectives of scientists, water lawyers, and policymakers in regard to successes and failures of applying legal instruments that use or do not use scientific knowledge. Most important, the volume will offer guidance on how HELP should bridge these two disparate communities' needs. A pioneering international meeting to strengthen communications between science and water law was held in 2001 at the University of Dundee. It was cosponsored by the American Water Resources Association (AWRA) and the International Water Law Research Institute (IWLRI) ("Globalization and Water Management: The Changing Value of Water," Dundee, Scotland, 6-8 August 2001); a special session was devoted to HELP. The above-referenced "paradigm lock" between the science and water law communities was strongly evident during that meeting and prompted the Wallace & Wouters, volume to be initiated by the UNESCO HELP Secretariat, the UK's Centre for Ecology and Hydrology, and the University of Dundee.

A second international conference (AWRA-IWLRI/University of Dundee International Speciality Conference: "Good Water Governance for People and Nature: What Roles for Law, Institutions, Science, and Finance?" Dundee, Scotland) was held on 29 August-2 September, 2004. A report from the HELP Global Call Evaluation Committee was presented during that event.

The International Water Law Research Institute of the University of Dundee, Scotland, will establish an International Centre for Water Law and Science that will also be the HELP Regional Coordinating Unit for Europe. This Centre will promote the integration of water law and science. An International Symposium is planned to be held in Dundee in 2008 to review the status of integration of water policy within the HELP basins.

3.4. THE IDENTIFICATION OF BASINS VULNERABLE TO GLOBAL CHANGE

The terms 'vulnerable' or 'sensitive' basins with respect to climatic variability and land-use change (LUC) impacts are commonly used. However, technical and socioeconomic criteria to determine which basins are vulnerable remain to be established.

Moreover, an overarching issue is the scale at which LUC impacts on streamflow are overridden by extreme precipitation events (flood-producing rains) associated with climatic variability. The current literature on this topic is sparse, and what literature is available suggests that headwater LUC impacts on streamflow are not detectable at larger scales (see Scott, et al., 2004; Archer, 2004) where climatic variability is the dominant factor. Furthermore, the threshold scale for LUC impacts may vary due to temporal and spatial changes in antecedent catchment wetness and the magnitude of different events (precipitation amount, intensity, duration) and so requires closer investigation. Further, emerging scientific evidence suggests that changes in terrestrial-atmospheric exchange of latent energy and water vapour arising from LUC (notably in the humid and semiarid tropics) could affect spatial and temporal distribution of rainfall, at least up to the regional scale (e.g., Amazon basin; Gash, et al., 1996; west African Sahel, Dolman, et al., 1997; Bonell & Bruijnzeel, 2004, eds). Such possibilities are particularly relevant where significant rainfall originates from "local" evaporation (precipitation recycling) as opposed to advected moisture of marine origin. In addition, LUC change vis-à-vis climatic-variability-impact on stream high and low flows is part of a current debate concerning impacts of forest conversion and resulting land degradation in the tropics. Despite contrary evidence from controlled headwater catchment studies (albeit limited in number), there may be some credibility (under certain environmental conditions) to widespread reports that forest conversion can increase stormflow and decrease dry-weather flow (Bonell & Bruijnzeel, 2004, eds.). Some of the research on these questions will build on existing programmes such as the World Climate Research Programme-Global Water Cycle Experiment (WCRP-GEWEX; http://www.gewex.org/), Dialogue on Water and Climate (now known as the CPWC or Co-operative Programme on Water and Climate; http://www.wac.ihe.nl/home.html) and World Climate Programme – Water (http://water.usgs.gov/osw/wcp-water/). For example, using HELP basins and within the framework of the joint WMO-UNESCO World Climate Programme – Water, a statistical (elasticity) analysis to detect hydrologic sensitivity to climate (Sankarasubramanian & Vogel, 2001; 2003) is being undertaken using the WMO-Global Runoff Data Centre (GRDC) and IHP-FRIEND (Flow Regimes from International Experimental and Network Data) databases. This analysis will be complemented by the use of simple water-balance models for sensitivity detection. Other analyses will employ a sequential nested approach (subbasin to basin) within a specific basin to detect differences across scales associated with LUC vis-à-vis climatic variability. Further, within the integrated scientific approach (outlined below) use will be made of existing rain radar and experimental catchment infrastructure to detect impacts of temporal and spatial movement of rainfields and land use on runoff hydrology across scales. When concerning floods, inclusion and outputs from the Forests and Water component below will enhance understanding. With respect to the perceptions and responses of stakeholders to "sensitivity" (floods and droughts) of basins to climate variability, three HELP basins (San Pedro, Thukela, Lower Murrumbidgee) have already contributed to the Dialogue on Water and Climate (2003).

3.5. FOREST AND WATER ISSUES

Forested catchments, especially in headwaters, are the principal sources of high-quality water for human and ecological needs in upstream and downstream areas. Thus, management of forests is a key IWRM component and requires further understanding of the biophysical interactions between forests and water. Moreover, there are critical upstream-downstream linkages such as devising policies and management strategies to provide upstream communities with incentives by downstream users that maintain biophysical values of headwater areas. In fact, baseline data are lacking on the hydrological function of headwater forested mountainous areas, notably in the humid tropics, upon which to base management decisions for allocating basin water resources. Such information is also required to scientifically assess hydrological impacts of global change. More research needs to be conducted on the ecohydrology of tropical montane cloud forests, which have a unique hydrology of cloudwater capture and special biodiversity values (Bruijnzeel, 2005).

Selected HELP basins will collaborate with the FAO FORC (Food and Agriculture Organization - Forest Conservation, Research & Education Service), EOMF (European Observatory of Mountain Forests), and CGIAR (Consultative Group on International Agricultural Research) system to implement the Shiga Declaration on Forests and Water 2002 and the EOMF Chambéry Declaration (June 2003; see References for details). Both declarations capture the issues outlined in the preceeding paragraphs.

With continued rates of conversion of 'old-growth' tropical forests, greater attention also is required to understand the hydrological impacts of afforestation-reforestation within catchments in various states of degradation. A UNESCO-led Symposium assigned one of its highest priorities to establishing tropical HELP basins. Such steps have already been taken by UNESCO-IHP in the Western Ghats in India, in collaboration with several partners.

3.6. ADDRESSING THE FOOD AND WATER POLICY ISSUE

There exist already some technological solutions to enhance water productivity (i.e., water-use efficiency in agriculture) linked with rainfed and irrigated systems (see, e.g., reviews from Molden (2003), Wallace (2000), Wallace & Gregory (2002)). Some available technologies (notably enhancing rainfed production and precision irrigation) need further testing in different hydropedological-hydrogeological environments linked, for example, with protection of food production against climatic extremes. Within a tripartite collaboration between the CGIAR-IWMI (International Water Management Institute), FAO, and UNESCO-IHP, scientific gaps will be reviewed and research strategies established for application within HELP basins nested in the larger Challenge Programme-Food and Water Benchmark basins (2002a,b).

3.7. NEED FOR A MORE INTEGRATED SCIENTIFIC APPROACH WITIN HELP BASINS

Over the last decade the Continental Scale Experiments of WCRP-GEWEX have pioneered an integrated science approach, especially in vertical and terrestrial atmospheric exchanges of energy, water vapour, and aerosols. A good example is the LBA (Large-Scale Biosphere-Atmosphere Experiment in Amazonia; http://www.gewex.org/lambada.html; Concise Experimental Plan, LBA, 1996).

In contrast, there is a global weakness in regard to taking an integrated scientific approach across disciplines in connection with lateral fluxes of water (quantity and quality). Two Pilot HELP basins are exceptions: the San Pedro (Varady et al., 2003; Browning-Aitken et al., 2006) and the nested sub-basin of the Red-Arkansas, the Little Washita, (both are part of the GEWEX Continental-scale International Project (GCIP) and the GEWEX Americas Prediction Project - GAPP). The UK LOCAR (LOwland CAtchment Research Programme and a UK contribution to HELP), presented elsewhere in this Special Issue, also is pioneering an integrated science approach by coupling surface-water-groundwater-riparian-zone process hydrology with instream ecohydrology.

To reinforce these developments, the IHP, in collaboration with the IAEA (International Atomic Energy Agency), has established specialised workshops for 2004-2007 called "Integration of hydrological and biological processes for sustainable water resources management" (see HELP website, http://www.unesco.org/water/ihp/HELP). The focus will be on water-quality processes and hydrological and ecological processes across scales connected with extremes. The coupling of process hydrology and the transport and fate of agrochemicals, for example, addresses HELP policy issues on water-quality impacts on environmental and human health. Here, it is worth noting that water-quality processes generally are far less understood than water-quantity processes.

An important objective of these workshops is to encourage experimental hydrology to emphasize larger mesoscale basins ($\sim 10\,000$ km^2) instead of traditional headwater basins (≤ 10 km^2). This will require new experimental designs to complement traditional. It is at larger scales that scientific outputs will be more practically valuable to IWRM while helping refine hydrological models.

3.8. HOW CAN SCIENTIFIC QUESTIONS BE ADDRESSED IN BASINS WHERE SCIENTIFIC INFRASTRUCTURE IS LACKING?

The HELP Task Force (Design and implementation strategy of the HELP initiative, 2001; http://www.unesco.org/water/ihp/HELP) examined this problem. One suggestion was to secure extra-budgetary funding to undertake a comprehensive, multidisciplinary assessment over a short, 6-12-month period called an Incentive Data Campaign, IDC. For example, the use of satellite technology coupled with spot ground-truth checks to verify basin geology, soils, and hydrological characteristics is critical to HELP's Assessment Phase. This intensive measurement campaign would describe the present state of a basin. Parallel surveys in the socioeconomic, legal, and institutional areas of water-resources management also would be undertaken. A second, Research, stage would involve a more detailed hydrological research programme developed from gaps determined from the IDC (Entekhabi, 1999, pers. comm.; HELP Task Force, 2001).

An alternative participatory approach in a basin in Mindanao, Philippines, has already been described by Deutsch, et al. (2004). This approach is linked with the impacts of land-use change (including forest conversion). With the support of local university researchers, NGOs and government agencies, drainage-basin data were collected by the local community using simple methodologies for six indicators to assess water quality and quantity, viz., community perceptions, suspended solids, altered streamflows, sediment yield, bacterial contamination, and demographics/land use. Simultaneous samplings of streamwater over time, for example, provided 'snapshots' of point-source pollution. Even with such a rudimentary database, the new information prompted improvements within the existing basin management plan. Further, this water-quantity and quality assessment enabled the most appropriate scientific hypotheses to be developed for a second, more traditional research campaign but with the important advantage of full community involvement.

It is worth citing two important statements from the conclusions of Deutsch, et al. (2004). "The startup of this collaborative project was relatively slow compared with research that does not involve community, but initial results indicate that the potential for lasting benefits and project sustainability are much higher than if attempted solely by a community, NGO, university or government agency." The same writers then go on to state that, "most scientists are aware that excellent and important research findings often go underutilized because they do not enter the political process. Instead, data remain in professional journals and away from meaningful action. The type of information needed by policymakers for natural-resources management planning should be science-based, but it need not meet all of the scientific community's requirements for precision and rigor. This is especially true in rapidly-degrading watersheds, with severe consequences for the community. There, application of partly-understood conservation practices, with full community involvement, may be far better than waiting for a “complete” scientific understanding”.

An expert group will be established to address this important question of how to undertake scientific research in the absence of technical infrastructure. Part of this group’s mandate will be to draw upon experiences from the HELP basin network.

4. Conclusions

Following the Kalmar Symposium recommendations, the global HELP secretariat at UNESCO, in collaboration with international and national partners, has outlined some key elements for implementing IWRM in HELP basins. Some of the strategic gaps will be addressed in terms of testing and applying new technical methodologies as part of the gathering of new information within IWRM. Most of the implementation of HELP, however, will take place within the basins themselves, consistent with the programme’s ‘bottom-up’ orientation.

HELP’s niche in contributing to IWRM is by defining knowledge and information gaps and then undertaking policy-oriented scientific research to support land-water management and policy. HELP is unique in that it has moved beyond words into action via a network of basins across the world. It is noteworthy that this network operates from mostly national sources of funding. A key incentive is the information exchange between basins and voluntary pairings of basins. As HELP progresses, the organizers expect that basins will be able to lever additional national and donor financial support. Some basins within the Pilot network are already reporting such derivative benefits. For example, the Motueka basin received a second tranche of significant funding in 2003 from the New Zealand Government. Elsewhere, the Mexican part of the transboundary San Pedro basin has been invited to apply for funding from the Global Environment Facility (GEF). In both cases, the IHP provided “networking” support whose prime objective was getting funds directly to the basins. Finally, the nature of HELP requires a medium- to long-term vision of research needs. Such values underpinned the success of the IHD (1965-1974), whose outputs continue to contribute to IWRM, and to land-water-related questions in the context of global change and climate variability (Bonell, 1999; Bonell & Bruijnzeel, 2004). Through the involvement and support of stakeholders within the HELP process, longer-term visionary values of research may be more quickly realised with subsequent benefits to society.

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PARTICIPATION ASPECTS IN THE REALISATION OF THE NETE RIVER BASIN MANAGEMENT PLAN: METHODOLOGY AND APPLICATION

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Abstract. Participation can be a valuable tool for River Basin Management Planning (RBMP), if used properly. In many planning procedures, participation moments are envisioned, but are poorly implemented due to an underestimation of the required time and effort. The design of an "integrated" river basin management plan requires participation as a medium for collaboration among policy domains, scientific disciplines and stakeholders. It is clear that the tools and strategies that are used for participation vary and depend on the stage of plan design, the objectives of the participation and the involved partners. A pilot-study implementation of a RBMP-methodology revealed a series of practical shortcomings and challenges. The success or failure of participation depends largely on an adaptive and flexible planning team that unites a great deal of insight in human nature with an adequate competence to support decision-making. Decisional support should have an appropriate level of transparency, accuracy, integration and complexity that complies with the type of participation and the type of decisions to be made. More effort should be put in the analysis of the stakeholder positioning and the creation of incentives for cooperation.

Keywords: Integrated River Basin Management, Water Framework Directive, Participation, Decision Support, PPGIS, Land-Use Planning

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1. Introduction

Public participation has become an aspect of major importance to many policy makers and has been embedded in many formal procedures for plan design. Also the European Water Framework Directive (EWFD) considers public participation as a necessity (European Commission, 2000). Yet there are numerous types and forms of participation and the practical implementation of it is mostly not that straightforward (Maurel, 2003). When many stakeholders are involved, policy makers are confronted with an overwhelming complexity, as well from the water system's functioning as from the many economical and social functions that are supported by the water system in a direct or indirect way. Often different goals and objectives are agreed upon, but are not assessed in a holistic way or are even adjacent in their implementation. Questions can be raised about reliability, stakeholder representation, procedural aspects, decision support, etc., Many planning processes are designed without a clear view on participation. Participation is then often seen as an obligation that can be fulfilled by inserting some participation moments. On the contrary, participation should be well-considered and embedded within a clear methodological framework. Participation can be successful if the right tools and methods are applied at the right moments. First we focus on aspects and difficulties related to participation and decision support that have been documented in literature. This knowledge can be helpful in designing strategies for successful participation and learning processes. This knowledge is also important to the team that guides the participation process as it is crucial to understand the psychology behind observed phenomena. Secondly, we describe a methodology for the development of river basin management plans and the function and role of the various participation moments. Finally, we discuss and conclude on lessons learned, experiences and recommendations that have resulted from the application of the methodology on the Nete-basin in Flanders.

2. Pilot Study Area

The Scheldt basin has a total area of 21.000 km², situated in three different countries. The main part of the Scheldt basin is situated in Flanders and the Nete basin is one of the 9 sub-basins of the Scheldt River. The Nete basin, with a total surface of 1.673 km², has an average population density of 343 inhabitants/km² and a total length of 2.224 km of streams (VMM 2001). The main part of the basin is situated in the province of Antwerp, close to the Dutch border. Although the Nete basin is one of the best-preserved river basins in Flanders and the water quality is fairly good in most of the streams, there are several problems with industrial discharges, diffuse pollution by households/ agriculture, a large historical pollution with heavy metals and the occurrence of inundations (Anon, 2001a). In the past, there has been limited attention for spatial planning in Flanders. The resulting fragmented land-use puts a mortgage on future developments of any kind and has significant impact on hydrological and ecological functioning.

2.1. ASPECTS OF PUBLIC PARTICIPATION

This section describes some aspects of public participation. It forms a reference framework for the analysis of the basin case as many of the experiences drawbacks are reported in literature or can be explained by it.

Level of participation: Different levels of participation can be used during the planning process. The concept of participation-levels has been introduced by Arnstein (1969) and has been used widely (Pröpper & Steenbeek, 1998; Van Ast & Boot, 2003). The government can play different roles and allow different levels of decisional power:

- Information: the public has access to information, which is a basic condition for PP.
- Consultation: the views of the public are sought.
- Discussion: real interaction takes place between the public and the government.
- Co-designing: the public takes an active part in developing policy or designing projects.
- Co-decision-making: the public shares decision-making powers with the government.
- Decision-making: the public performs public tasks independently.

Type of public participation: There are two main types of participation according to Van Ast (2003). The pluralist type involves the broad public in a non-organised way; the corporatist-type involves representatives of stakeholder groups.

Driving forces: The need for a plan can be acute, demand driven, can be externally obliged or can grow from a public awareness that there is a need to regulate ongoing trends. The perception of the different stakeholders on the problem can be different at start but is susceptible to change during the process.

Level of interest: An important condition for stakeholder participation in decision-making is the level of interest that one has to take action or make decisions. If this incentive is not present, the partner has to be convinced in achieving a social or community goal through the process of research (McTaggart, 1991;

Parkes & Panelli, 2001). Explicitly formulating the goals of the participation and reflecting on which decisions can be made by the stakeholder is thus essential before proceeding on the issue. Acknowledgement of the problem and setting the scope of possible contributions to the solution is solving half of the problem.

Stakeholder positioning: A second and most important aspect in public participation processes is the position of the participants and their participatory relationships. Considering experts and agencies as participants can raise issues on equity and access to information when not applying the right participatory model. Goff (2000) categorized participants as:

- Co-researchers: those publicly recognized as responsible to act on the issue
- Critical reference groups: those who bear the consequences of the actions
- Facilitators: those who need to develop research methods to find the answers

Negotiation and communication strategy: The applied negotiation and communication strategy can have significant consequences on the result. Purely distributive negotiations imply that where one benefits, the other(s) loses. Integrative negotiations are focused on establishing a common vision. The integrative negotiation strategy is preferred from a participation viewpoint although the distributive form of negotiation might be inevitable in many cases. Often the 'learning process' is not applicable to the interest groups forcing delegates to shift towards distributive negotiations.

TABLE 1. Interactive communication strategies (Van Woerkum, 1997).

Distributive negotiations	Integrative negotiations
Starts from positions	Starts from vision and interests
Incommunicative (closed) on revealing intentions	Communicative (open) on revealing intentions
No joint fact-finding	Joint fact-finding
High demands (high bets)	No demand position
Threats	No threats
Less mutual understanding	More mutual understanding
Low learning effect	High learning effect
No concern for others	Concern for others

Decision support: There are a growing number of decision support systems (DSS) going from analysis of information, towards modeling of scenario's and finally modeling the optimal decision. For each of the phases in the EWFD implementation, models can be used as tools to guide, support, monitor and evaluate policies (Rekolainen et al., 2003). Over 20 different information and communication-tools have been analyzed for the HarmoniCOP project of the

European Commission (Craps & Maurel, 2003; Maurel, 2003; Maurel et al., 2004; Ridder et al., 2005). The models are used to provide a scientific support to substantiate decisions on different levels and can be used in public participation processes. As the DSS becomes more and more advanced, socio-economic modeling can be included to find the optimal solutions. These models can be considered as decision-making models (DMM). From that point on the public-participation issue will be on 'how to define and value these objectives'. The success of a DSS in a participatory process depends on various factors (Newman et al., 1999). First of all the quality of the input data and the model itself will determine if the model shows adequate and credible results. Secondly the system needs to be trusted by stakeholders and end-users (independent of the quality of the model). Internal opposition by senior-executives (Poon & Wagner, 2001) and distrust by stakeholders can arise because the underlying theories of the model are not understood. Very sophisticated models might show excellent results but could fail due to mistrust by stakeholders, inaccessible software, DSS-complexity, lacking data, lack of field testing, internal opposition and a poor ease of use. The use of complicated models might result in estrangement of the necessary partners for decision-making. Some criticism suggests that the use of PPGIS (Public Participation Geographical Information Systems) is restrictive, elitist, and antisocial (Clark, 1998). The early involvement of users and stakeholders, transparency and the user-friendliness of the model are essential factors of the success of a DSS. The use of complex models can be indispensable to experts but might be concealed for public participation by investing in a good preparation and communication strategy (limited number of scenario's, concrete cases etc.) on results including a reliability assessment (e.g. by field testing of results).

Decision-making pitfalls: Many decision support systems attempt to value alternative scenarios in hard currency and present that information as a decisional support. In consequence of reductionism and uncertainty of these models, they usually are unable to compare long-term scenarios. The option of delaying or waiting to decide has been found to be a valuable and often overlooked alternative in many decision support models. This concept originates from economical engineering and is applicable to any universal uncertainty decision-making. Herath (2001) gives an overview on the option value concept and the decision models that are based on the concept. Examples of environmental oriented applications: forestry (Insley, 2002), land-use planning (Schatzki, 2003) and biodiversity preservation (Kassar & Lasserre, 2004). The real option rule is that one should invest today only if the net present value is high enough to compensate for giving up the value of the option to wait. It is commonly found in the natural resource industries, where commodity prices are a significant factor for investment and development strategies. In adopting environmental policy, there are two types of irreversibility (Pindyck, 2002). On the one hand policy irreversibility and on the other hand environmental damage irreversibility. They both originate from uncertainty and irreversibility. The choice to implement or not imposes a chance for costly scenario's when not making the right choice. The first scenario is when implementation of policy has been done, but it wasn't necessary and the second scenario is when there was no policy effectuated (or to late) and irreversible damage has been done to the environment.

Stakeholder representation: Rosenbaum (1989) stated that with an increasing number of stakeholders in deliberation processes, it is less likely to attain consensus between policy makers and interest groups. It therefore might be necessary to select only major stakeholders or to aggregate multiple stakeholders under a representative body. Another option is to use public surveys and stakeholder interviews to include public concerns. However this approach has the disadvantage that it will not lead to growing public awareness about environmental problems. A growing gap in maturity level of the stakeholder representative and those who he represents can lead to alienation and questionable legitimacy.

Psychology of changing opinions: Be aware of historically grown prejudices and seemly irrational reasoning. Having pre-existing opinions or preferences before the participation process makes people seeing only the facts that consolidate this opinion and neglecting or minimizing facts that contradict that opinion (Russo et al., 1996; Eisele, 2003). Groups who are put in a defensive position or have great mistrust are very susceptible to taking harsh positions. Svenson (1992; 2002) defined 3 differentiating processes related to problem solving. The first is called Holistic differentiation and implies subconscious, emotionally laden associations leading to a fast and harsh decision (Shamoun & Svenson, 2002). The second is process-differentiation to explore alternatives by applying certain decision rules. The third type includes three aspects in coming to a final decision: a) re-structuring the attractiveness of different options and making one alternative look brighter that others b) re-structuring all the facts to support a preferential decision c) finding additional supportive aspects to support a decision (Shamoun & Svenson, 2002). Eisele (2003) also investigated the relation between decision preferences of a group and its individual members. He showed that depending on group-member interactions and information distribution between the members there can be a great difference in post-decision consolidation. Smaller groups have better information flow through and have better changes to consolidate a decision as a group. Whereas larger groups, representing many people, having a tendency of being divided about the decision that has been make.

Gaining trust in participation as a conflict resolution tool: Beierle (2002) examined and compared a large number of case studies in environmental decision making to asses the quality of stakeholder-based decision-making. He examined the cost-effectiveness of out coming solutions, contributions of innovative ideas from stakeholders, occurrence of consensus decisions (joint gains) and the substantiating of decisions (with technical or scientific information). The outcome was that the quality of decision-making is higher with intensive and longer participation processes. Other findings were that stakeholders tend to be very critical on the quality of the facts and create an incentive for more and better data gathering and analysis, new research projects etc., This skepticism is often not present within the governmental agencies and may reveal questionable science or reasoning. According to Darnall (2004) public involvement seems to be less effective when there is a shortage on concrete information. The interest of the public (stakeholders) seems to be lower or to abstract in the beginning of a planning process. It can be concluded that public participation has added value when dealing with well-documented cases. However public participation is popular, it might be a threat when there is a hidden motive for policy makers to make stakeholders jointly responsible for the decision because the decision is ill substantiated due to uncertainty. Hence, the mistrust and skepticism of stakeholders towards governmental agencies is a necessary evil.

When considering all of the aspects related to public participation, it is clear that public participation is not the easy solution as it appears to be. The socio-economic and psychological complexity comes close to that of the water system, making decisions not easier to take. But at least there is (a feeling of) a shared responsibility when making the wrong decisions. Maybe one of the greatest incentives for authorities to implement participation is not having the answers themselves. Public participation can be a pitfall for those who believe that a collective decision is the right decision.

3. Planning Process for RBMP in Flanders

The entire planning process for the development of a river basin management plan (further on called RBMP) is visualized by the scheme of fig. 1 and consists of different planning process phases (Staes et al., 2003; D'hondt & Van den Belt, 2004). The gathered environmental and stakeholder information need to be unraveled and summarized by an issue analysis. Goals and objectives need to be set on these issues from a water system perspective. Next, the means and measures on how to reach these goals and objectives need to be discussed on an administrative and stakeholder level. Finally decisions need to be made and formalized into a long-term vision, actions and measures.

One of the primary information pillars is a **stakeholder analysis** (a) to document and quantify the interactions of stakeholders with the water system (Anon, 2001c; 2002). As a part of this analysis, each stakeholder and municipality was given the opportunity to quote water related conflicts from their own viewpoint. The stakeholders were contacted by interviewing them or by sending a questionnaire (b). The issues were kept in the same terms as the stakeholder stated it. If possible accompanied by information about the type (quality, quantity, ecology...), location, possible solutions & opportunities, probable causes, who's to blame. The issues were inserted into a (geographical) database (c) and categorized according to the stakeholder group and thematic issues. This information and other documents were made accessible for the broad public by a website application (including a GIS-application). The **water policy plan** (d) (Anon, 2000a) was already available at the start of the project and describes concepts, scientific based procedures for research & monitoring, public participation, socio-economical relevance and policy intentions regarding integrated water management in Flanders. It also describes the main stakeholders and their impact on the water system. The full title is "integrated water management in Flanders: concept, methodology and structures" (Bergmans et al., 1998). The principles and actions that are applicable to the basin are to be implemented and comprise also guiding principles for discussion and evaluation. The **environmental analysis** (Anon, 2000b; 2001b) is a combined GIS-database and text report that bundles all available information regarding hydrology, hydrogeology, landscape, soil, nature, land-use, water quality, juridical aspects, policy plans etc...

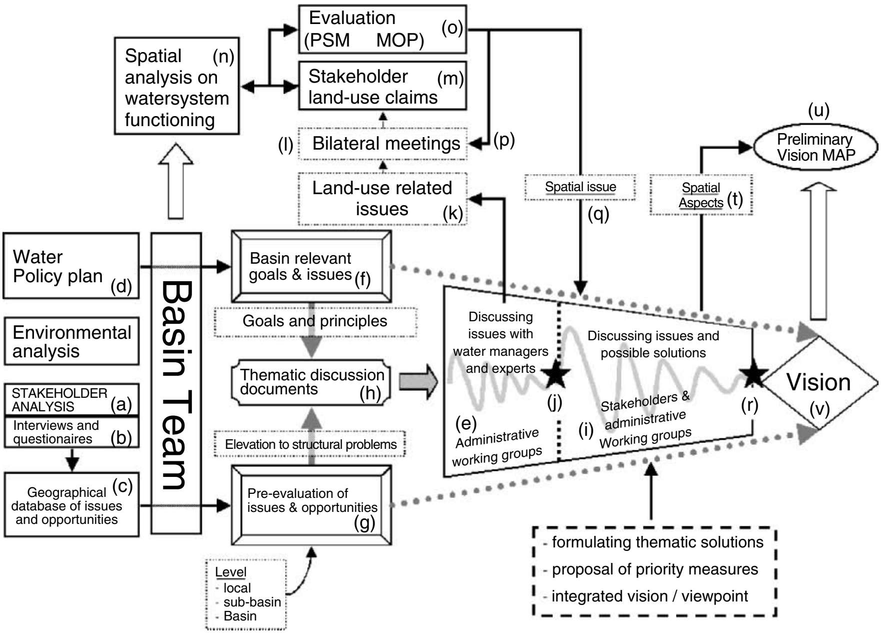

Figure 1. Conceptual planning scheme for the development of a RBMP

A first real step towards the basin plan that included participation was the elaboration of so-called **administrative working groups** (e) for which all relevant administrations and experts were invited. The issues are documented, aggregated and subsequently submitted to a team of experts, and basin authorities for setting commonly accepted priorities, goals and objectives. They analyzed the 'quoted' issues, compared the stakeholders' viewpoint to the authority's viewpoint, discussed possible solutions and decided which should the appropriate administrative level to deal with it. To bring the low-level issues to a more fundamental problem definition, a viewpoint from the water system was needed. Initially, the water policy plan was applied on the Nete-basin characteristics (f) to point out structural basin functioning and related problems. After reaching consensus about the problem definition, (long term) goals and objectives, there is a necessity to take actions, create instruments and measures to reach those goals. Because of the diversity of issues, they were categorized thematically (g) and elucidated from a more holistic viewpoint. From this stage on flexible **thematic documents** (h) were created which would grow throughout the planning process as more information was collected. The basic thematic documents contained now a selection of issues, brought together in a more general problem definition (theme) followed by a viewpoint from the authorities and background information on the subject. The next step is the confrontation with the stakeholders in **multi-stakeholder workgroups** (i). At this stage an information session was organized (j) to inform all people who were addressed during the stakeholder analysis and to invite them to participate in the stakeholder working groups. In these groups administrations, invited experts and stakeholders can discus the topics and individual issues extensively and finally come to long-term vision alternatives on the basin and some short-term actions and measures.

The first aim of these participatory working groups is to discuss the often biased and one-sided issues from multiple viewpoints of stakeholders and water managers. Once there is consensus on the problem definition and related water management issues, it was possible to discuss possible policy interventions, actions and measures, which in their turn need to fit within the higher level management policies and priorities. It was not possible to reach consensus on each of the issues, but looking at the time-scale we had it was already a big achievement that the different aspects of issues were explored and discussed. In some cases the subject matter was primarily on which information was needed for making the management decisions.

Some thematic issues were of such nature that a basin wide analysis of the issue was necessary (k). It appeared that many problems originated from unfortunate choices in spatial planning and land-use. In respect to this key problem a **spatial analysis** was done to analyze and advise on actual, planned and future land-use in relation the water system. On the one hand we needed to analyze the

water system functioning (n) and we evaluated the physical potential for water conservation, flooding and infiltration (combined with vulnerability for run-off and soil-erosion). To get some idea of possible future developments in land-use, bilateral meetings (l) with sectoral stakeholder representatives were organized. In these meetings they could select and combine existing maps or drawn up maps into a **stakeholder land-use claim** (m), which we have called a practical suitability map (further called PSM). Each PSM actually represents the relative importance of an area to be maintained or developed for their sectoral activities. On the other hand a map of opportunities (MOP) was needed to reflect the viewpoint of the water system. For each of the PSM's a counterpart MOP was created that shows where, based on objective physical aspects, the water system can fulfill the needs of a sector in a sustainable way.

The same approach was used for some water system aspects where water managers designate the desirable infiltration-, water conservation- and inundation areas (to preserve or restore).

The basin management plans need to address a long term vision on spatial planning from the viewpoint of the water system. The spatial analysis is intended to provide a tool for land-use planning that reckons with the potential for restoration or preservation of the water system functioning. The natural water retention in wetlands is needed to overcome dry periods providing a slowly released base flow to rivers; water storage is needed to protect downstream areas from excessive flooding and infiltration is essential in both replenishing the groundwater reserves and to decrease the magnitude of peak flows. Any of these functions are of crucial importance to the overall system functioning and provide hydrological stability.

The concept of the spatial analysis is to delineate areas with possibilities for mitigating impact on the water system, find potential restoration areas for water system functioning and to effectuate a standstill in negative impacts for relatively unharmed areas. Experts made up a map with a suitability gradation for a stakeholder activity. In addition, the stakeholder makes up a suitability map for their claim on the land. By confronting these maps, areas for evaluation are delineated (stakeholder claim but unsuitable according to experts). By an additional gradation with regard to the actual spatial destination, land-use and existing protection status, it was possible to detect areas with an opportunity for discussion.

The **confrontation of the PSM and MOP** (o) revealed the conflict, consensus and opportunity areas which are subcategorized according to the discrepancy (between MOP and PSM) and to which extend the claim is justified from a legal point of view (spatial destination, legal restrictions, actual land-use). Using field knowledge of the actual situation and background information, the conflict areas are assessed and selected by experts on their seriousness and possibilities. The sector was invited to a second round of **bilateral meetings** (p) to discuss the conflict areas. During this bilateral meetings errors could be detected and agreements could be made about solutions (mitigation, compensation, etc...) for the possible conflict areas. After attaining an acceptable bilateral vision on the area, it might be necessary to discuss some conflict areas in the multi-stakeholder workgroup (q). Due to time pressure, the full potential of the methodology could not be used. Therefore a multi-stakeholder workshop (r) was prepared to test the methodology. The test cases were related to problematic flooding of downstream areas. Based on the spatial analysis a selection was made of possible suitable inundation areas. For each of the areas, the spatial analysis was used to guide the discussion between stakeholders. Some of the cases were adequately resolved and should be realized within the next 6 years.

This **spatial database** of maps is also used to illustrate topics that are related to the spatial aspects of the basin. In this way there is an interaction between the conclusions of thematic working groups and the spatial analysis of the basin. Practice proved that the use of this spatial database was a very simple and transparent way to analyze various questions that were posed by participants. Very specific questions about combinations between multiple maps could be answered immediately due to low computation time in combining the grid-maps (e.g. the occurrence of maize in areas susceptible for flooding and that have a 'green' spatial destination). Possible conclusions on spatial aspects (t) need to be added to the preliminary spatial vision map (u). It showed that it is difficult to come to a final solution or major changes as it takes much more time than available to evaluate the different alternatives. Nevertheless, the first RBMP pointed out the essential subjects of discussion and documented it with different viewpoints, objectives and a holistic approach, which is a solid basis to continue on. Secondly an instrument was created that can easily be used to prevent additional undesirable developments within the basin, by posing the correct requirements (mitigating, compensating, restrictive, financial incentives, etc.,) on permit applications and changes in spatial destination plans. In this way the spatial analysis may be used to impose constraints on future developments without deciding on the remaining options. This approach is in fact a very simplistic way to maintain the option value of decisions by preventing hazardous and irreversible decisions.

Finally a document (v) is created that bundles vision alternatives, actions and measures. A preliminary long-term vision map (u) summarizes the spatial aspects of the plan. This document needs to be approved by the government and subjected to a public survey before implementation.

4. Discussion

Throughout the whole planning process, the implementation of the methodology has been facing problems. It showed that stakeholder representation and its internal organization is crucial for success. Lessons are also learned on strategies to improve the participation process itself. At last we denote some difficulties regarding the creation of incentives for participation and stakeholder strategies in decision-making.

Stakeholder representation and organization: In a developed country with high pressures on land-use, we have many stakeholders. The number of individual stakeholders and the interrelated issues make it necessary to use a corporatist type of participation and work with stakeholder groups. An individual stakeholder should of course be consulted when reaching a project-level. Until then, the stakeholder group must represent all of those individual stakeholders in an objective and sensible way and preferably comply with three conditions. The first condition is that the stakeholder group representative must be representative and should be chosen by the stakeholders. Secondly, the stakeholder group representative should have an objective long-term vision, which is supported by the majority of stakeholders. Finally, there should be consultation and communication within the stakeholder group. The unforced development of such structures is a slow and costly process. In the meantime, it is unclear who should be addressed to represent a stakeholder group. It was shown that even within stakeholder groups there is no consensus and that there is no internal communication about these topics. This lack of internal organization by stakeholder groups makes it difficult to designate representatives which function as a legitimate partner. Representatives often give their explicit personal opinion or do not want to speak for the stakeholder since the stakeholder has no or doesn't want to take a position for others. However mostly the same people attended the working groups, it was difficult to deal with new people joining along the process because that resulted often in a setback on the discussion level. It was also experienced that there was insufficient internal preparation and deliberation on behalf of the stakeholders since different people, though representing the same stakeholder organization, often had different opinions. If the stakeholder group does not organize itself properly (facilitated or not), there is no partner in negotiating.

Another problem we noticed was that depending on the financial and organizational level of a stakeholder-group, there was a stronger representation. The relative cost for an organization to designate someone can vary significantly. It is a difficult issue whether stakeholder representation is equally distributed. Stakeholder representation can depend on the following factors: economic and financial power, organizational capacity – diversity within stakeholder group, intellectual capital – knowledge is power, mobilization capacity – number of involved people, starting position - threat or opportunity and how crucial their cooperation is to attain results.

How should the stakeholder groups then be selected and represented? When do we consider a group of individual stakeholders as a group? Allowing each stakeholder-group to send one person demands solid internal organization of the stakeholder groups. Allowing an unlimited number of stakeholder representatives, results also in an unbalanced representation due to the financial situation of specific stakeholders or the number of individual stakeholders.

An example is the representation of tourism as a stakeholder-group. The stakeholder group has of its own a great diversity, consisting a large number of individual stakeholders with each of them often having only interest at a local scale. Because it is a hard working business and there is no organizational alliance, there are only few people who have the time, knowledge or altruism to speak for an entire stakeholder group and not only for their individual interest.

It is clear that a high level of stakeholder maturity cannot be reached within the time that was given for developing a first basin management plan. Secondly it is a drawback that the participation process cannot continue on a regular basis and increase in stakeholder maturity towards a next basin management plan. Putting forward financial compensation for stakeholder participation and organization might result in a better partnership and plan efficiency on the long term.

What to participate on? Looking at the complex socio-economical society where it is difficult to even agree upon straightforward issues, it is clearly even harder to agree upon ambivalent decisions. Environmental issues are almost always of an ambivalent character. There is no ‘right’ decision that complies with everyone’s interests. There is an enormous challenge to agree on why, how much and by which means we protect our environment. Participation on water management is a difficult process because the complexity of the system makes it incomprehensible for most people. Problems need to be made tangible and comprehensible by structuring the problem. Discussions are likely to be more productive when the subject has an outlined scope and is fazed into progressive steps: (1) Formulating problem definitions; (2) Setting objectives, goals and constraints; (3) Listing alternative solutions; (4) Making Decisions on concrete actions.Each progressive step gains in complexity and makes public participation more difficult. Defining the issues and problems is relatively easy as there are no value judgments attached. The second stage is much more difficult as it holds a value judgment. As objectives might conflict there is a need to value or prioritize objective realization and to determine indicators that show us to which extent the objectives are met. Often the second step is divided in two steps, as it is easier to find consensus agreements on “guard watching” constraints that determining the scope of objective realization. One main problem on setting objectives is the time scale that should be considered. The appreciation of objectives that relate to sustainability is susceptible to socio-economic changes and changes over time. The difference in value judgment on short and long-term objectives is also linked to this. When choosing not to reach certain objectives in the future, it could be seen as a loan that has to be paid in the future. This aspect should be transferred into the decision making balance as an aggregated deficit. The option value of decisions should also be incorporated into decision-making. The option value is determined by the irreversibility of a decision. When options are open, the total value is an aggregated statistical sum of all the possible scenarios. However these theories appear logical, they are difficult to put in practice.

Moderating and facilitating participation: An objective and strong moderator is necessary to keep the public participation process in hand. Keeping in hand harsh discussions or blocking long monologues demands some diplomacy. Practical agreements on subject scope and speaking time can be made but are difficult to enforce in a non-obligatory meeting. The overall feeling of contentment on the participation process by the participants was monitored to some extent. Each participant was asked to fill in a short inquiry after each session. It posed questions about the moderator's performance and neutrality, if the participant considers his presence to have added value to the outcome of the discussion, whether he had sufficient background information or knowledge on the subject, if he had obtained new insights or information during this session, etc. The maps that were developed for the spatial analysis turned out to be very sensitive material. There is a risk that maps can be used outside its context to be abused when it's supportive to ones goals. Maps tend to have a certain power and have also a strong psychological effect. A map can give people the feeling of being a threat that locks in future possibilities. The fear that this map is the endpoint of debate makes it extremely sensitive material. This is described by Harley (1988), Van Eeten (1999) and Rein & Laws (1999), who speak of unconsciously perceiving 'hidden messages' within maps and the framing-effect. Detailed visualizations can easily lead to endless discussions about spots and lines, even resulting in strong polarization, mistrust and a completely blocked participation process. It is thus indispensable that stakeholders, experts and facilitators have insight into the different map-types and their function in the (whole) planning process. This has been felt very clearly during the elaboration of the "stakeholder claim maps" for the spatial analysis. Some participants were very anxious to lose even one square meter out of sight, complaining even about the resolution though there was no intention to delineate at a parcel level. At first it resulted in the creation of unrealistic maps. Example: although agriculture is to be declining in the spatial balance they even claimed all unbuilt areas in the suburban areas. The use of a wrong legend due to hasty work was the cause of a high tension with allegations of having hidden motives and framing. Some stakeholders strongly hesitated to differentiate the strength of their claims on land-use, although it would be in their interest that the plan could differentiate its actions in consistence with the local agricultural practices and its value. Only after intensively explaining the concept, a differentiation could be made on land-use, destination, soil properties and socio economical status.

Incentives for commitment and cooperation: Whether a stakeholder cooperates in the participation process depends on a number of criteria. It is crucial for the planning process to have information about stakeholder positioning and use the information in a strategic way. Hence it is important to look from the stakeholders' viewpoint. The balance of threats and opportunities from the viewpoint of a specific stakeholder will determine if the stakeholder is likely to conduct a cooperative or an obstructive strategy. Mostly, the stakeholders have a gut feeling about the threats that will arise during the process. A specific issue can also be approached from the stakeholders' viewpoint. When dealing with an issue the benefits and costs of the current situation need to be explored and allocated to stakeholders. Secondly, when exploring the alternatives, gains and losses under alternative scenarios should be explored and designated to the different stakeholders. A strategy would be to combine an equal amount of threats and opportunities in one meeting and to trade-off between stakeholder interests. Because this is hard to quantify and even harder to put into practice, there could be a preceding bilateral meeting with stakeholders to find those opportunities (interests) and create incentives for cooperation. Another issue is the influence of political and legislative forces on the planning process. More often the participatory meetings have no authority at all. Legislative rights regarding policy planning can lead to difficulties when trying to implement PP in the planning process. When (individual) stakeholders have a legal right to object to the final plan and conversely, the participation process has no legal authority at all, there is little incentive to take the participation very seriously. Therefore there should be intermediate decisions or at least document or reports in which commitment and agreement statements are officially stated. If not, there is no guarantee for either the makers of the plan or the stakeholders that agreements on a previous stage will stand the next phase of the planning process. Stakeholder representatives might attend, but there is no real incentive for full engagement. A probable symptom of this might be the observed absence of clear statements due to weak communication between the representatives, the stakeholder organizations and its members. This is particularly present when there is no incentive for a stakeholder to participate or is even forced into a defensive position. As the participation has no authority, it is bound to integrative negotiations whereby it is essential that the stakeholders see opportunities in the participation. If the participation would have a certain authority, there is a worse scenario for the stakeholder (stick behind the door) when not cooperating in the process (e.g., uniform measures instead of regionally differentiated measures) and distributive negotiations become possible.

The problems regarding stakeholder commitment also originate from the fact that most decisional authority is largely embedded in other policy domains or higher authority levels, making the authority of the basin management plan dependent on the willingness and cooperation of these instances. During the planning process, a large number of dusty plans emerged and several old and new insights were put together. Remarkably all this information was scattered along the various partners in water management authorities. The accessibility of these bureaucratically made up plans was very poor, but when discussing certain topics, some of those plans appeared on the table. Secondly the stakeholders issued many structural conflicts regarding existing policies and regulations. These topics were difficult to handle because they fell outside the authority of the basin plan. It is a clear indication of the problems that are related to the scattered competences and the resulting incoherence between the various policies and regulations. Although the implementation of the water framework directive clearly states that al plans should be in accordance to the river basin management plans. It is often seen that the attitudes of the archaistic administrative system are still persistent. Often plans that are in the pipeline are retained from discussion for strategic reasons. The idea there is that it is better to mitigate or adapt existing plans with the excuse of not knowing instead of getting advise in advance and being bound with that advice. If this strategy is successful in getting around the restrictions of the RBMP, it will undermine adequate water management. Local municipalities even showed a great hurry to submit permit applications (e.g. building projects) of which they know they wouldn't be approved by the RBMP. These cases show that the threat of the EFWD can be an incentive to realize (irreversible) changes when it is in people's personal interest. A fast and strict implementation of the EFWD is essential for its success.

5. Conclusions and Future Developments

Participation can be valuable tool for the development of RBMP if applied within a clear methodological framework and guided by a competent planning team that can overcome the shortcomings that are typical for deliberation processes. The study also reflects that a culture of collaborative planning can not be created instantly, but needs to grow on both policy makers, planners and stakeholders. Understanding the different aspects, needs and difficulties regarding participation can aid policy makers to facilitate the process of stakeholder organization, trust building and integrative cooperation. The presented methodological framework can be adapted and expanded for application on other basins without affecting the conceptual backbone of the approach. There can be improvements by adding more sophisticated tools to the water system functioning and spatial analysis such as geo-hydrological modeling, water allocation models, assessment of land-use scenarios, cost-benefit analysis etc…

Regarding the practical development of integrated decision support, there is a need for a simple and transparent model that can be easily applied, aggregate information and that can focus attention on the policy questions. The overall policy question is how to reach sustainability and good ecological status with the least cost and maximal social acceptance. The spatial analysis tool we have used could be improved and expanded by adding a basin perspective to it. This method can be used to balance the need and benefits for additional measures in upstream areas with respect to their effect on mitigating the downstream system vulnerability for not meeting ecological or function related objectives. It is by that way measures can be distributed spatially in a cost-effective manner.

Participation in its current status does not allow real decisional power and is more a tool to explore the different opinions and viewpoints through discussion. The current shortcomings reveal that a attributing a higher level of decisional authority is presumably not desirable or achievable. As we have to use integrative negotiation strategies, more efforts should be put forward in analysing stakeholder positioning and the creation of incentives for participation. Ongoing participation and cooperation on both policy and stakeholder level is a necessity to grow towards an adaptive and integrated water management.

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THE USE OF HYDROLOGICAL CHARACTERISTICS FOR WETLAND HABITATS PROTECTION IN WATER MANAGEMENT OF THE UPPER NAREW RIVER SYSTEM

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Abstract. There is a growing pressure on use of the water resources but at the same time, there are growing concerns on the ecological status of surface or ground water dependent ecosystems. Riparian wetlands belong to this group. The ecological characteristics, which describe the status of riparian wetlands, are mostly connected to the phenomena of flooding. In this paper main flood characteristics i.e. flooding area, average depth of flooding and flooding frequency were used in order to evaluate the best release policy of water reservoir located upstream from the protected wetlands. The hydrodynamic model coupled with hydrological models of tributaries and water balance model of water reservoir was used for this purpose. It was found that only average flood can be impacted by the reservoir policy. Extreme events can not be controlled and very small floods can be increased by the reservoir operation in combination with water release from the drainage schemes located on major tributaries.

Keywords: water management, hydrodynamic modeling, flood, GIS dynamic analysis

1. Introduction

Intensification of water resources use in the river basin due to the economical and social development brings the new challenges in water management. As the shortage of water endangers riparian wetland ecosystems the environmental

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flow in the river should be maintained in order to protect or restore them. It means also that in the river basin, wetlands become one of many water users of the water resources. The question is how to asses the magnitude of the environmental flows and which characteristic of such flows might be used in the decision process about water allocation.

The best management alternative is chosen with the help of different decisions criteria, describing the consequences of water deficit. One of the widely applied methods is use of the mathematical criteria - reliability, resistance or vulnerability proposed by Hashimoto et al. (1982). In order to use these criteria in the multi-objective optimization process number of mathematical indices was proposed by Fiering (1982), Duckstein & Plate (1985). The time guarantee, volume guarantee, average water deficit, average time of the deficit belongs to the most often used indices for describing the difference between the required and actual state of the water systems elements. Recently Loucks (2000) proposed to use the system characteristics which can describe the social, economical and ecological values of the particular elements of the system. Having the system characteristics and indices of difference between the optimum state and actual values, it is possible to calculate the criteria of reliability, resistance and vulnerability in the sustainability context.

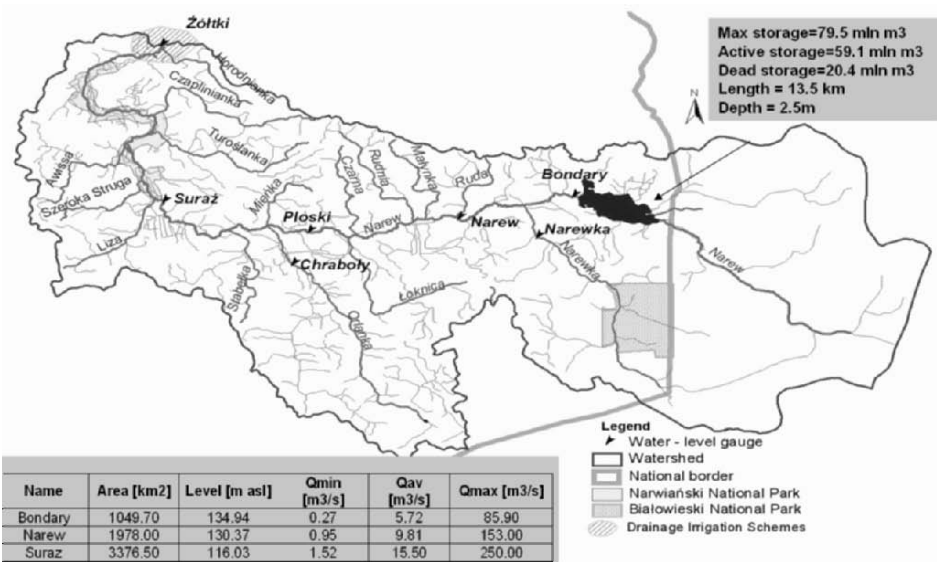
The ecological characteristics, which describe the status of riparian wetlands, are mostly connected to the phenomena of flooding. According to the two main ecological concepts of the “river continuum” (Vannote et al., 1980) and “flood pulse” (Junk et al., 1989) riparian wetlands should be inundated in order to gain the biochemical input for plants development and bring some invertebrates and fishes on the floodplains for the recruitment and spawning. There are a very few works describing the characteristics of flooding phenomena needed for their protection. In the most cases, there is a postulate of not changing the historical conditions of high flow phenomena, what is a very difficult requirement to meet in the conditions of growing pressure for use of water resources. However, according to the works of Oswit (1991) or Hooijer (1996) the most important flood characteristics for plant communities’ development are: flooding area, average depth of flooding and flooding frequency.

Hydrodynamic models seem to be the most appropriate tool for obtaining this type of characteristics for the riparian wetlands. With the use of properly calibrated model, it is possible to calculate inundation characteristics for the whole floodplain using as an input data discharges measured on the gauge stations. This approach has been applied for the Upper Narew River system, where a conflict arises between farmers and ecologist about water release policy from water storage reservoir.

2. Description of the Upper Narew River System

The area of the catchment of the Upper Narew covers approximately 7300 km^2, the rivers' hydrological regime is typical of those for the lowland rivers of Central Europe. It is characterized by a single spring flood caused by snow melting, and quite a balanced summer runoff. Raised water stages in summer occur occasionally. Given the morphological conditions and economical development of the region, two reaches of the Upper Narew river valley can be distinguished (Fig. 1).

The first reach extends from the Siemianowka reservoir to the narrowing of the valley in the vicinity of the Suraz settlement. It is a relatively narrow valley, which is flooded for a short time every year. Its nature is typical of marshy meadows becoming dry-ground forests. The biodiversity of this area is caused by a rich surface water network; coexistence of natural meadows, bushes and small forests with the extensive farming. The valley forms a breeding ground for three species threatened with worldwide extinction and is one of the ten most important refuges in Poland for at least 22 bird species. The natural conditions favor this area for landscape protection, tourism and agriculture. However most of the natural values of this part of the valley strongly depend on water conditions, especially on the occurrence of the spring flood.



Name	Area [km2]	Level [m asl]	Qmin [m3/s]	Qav [m3/s]	Qmax [m3/s]
Bondary	1049.70	134.94	0.27	5.72	85.90
Narew	1978.00	130.37	0.95	9.81	153.00
Suraz	3376.50	116.03	1.52	15.50	250.00

Figure 1. The hydrographic system of the Upper Narew River

The second valley reach includes the wetlands between Suraz and the Zoltki weir. In 1994 the Narew National Park (NNP) was established to preserve the unique nature of this part of the valley. The Park is an area with the outstanding natural values, including unique systems of plant communities, favoring the existence of the variety of bird species. It seems, however, that local conservations measures may be insufficient to maintain wetland processes because the level of surface waters in the Park depends to greater extend on the water resources in the upper part of the catchment than on its own resources. The basic objective of water management for this area is maintenance of flow rates in the river which ensure the appropriate soil moisture in the surrounding marshes.

The Siemianowka Reservoir started its operation in 1995 after 17 years of construction works. The total capacity of the reservoir is equal to $79{\cdot}10^6 m^3$. It was planned at early sixties, as a water reservoir supporting the huge investments in drainage of Narew valley wetlands. It was assumed that the reservoir would fulfill several needs:

- to irrigate peatlands of the Upper Narew and Suprasl Rivers
- to supply waterworks of city of Bialystok
- to increase low flow characteristics of Narew and Suprasl Rivers in order to improve their water quality,
- for fishing.

In the meantime the political and economical situation of Poland has changed. Moreover the ecological value of wetlands become so important that instead of drainage, the Narew National Park (NNP) was created in the middle part of the valley. Bialystok city water works after introducing the financial instruments for water saving uses only half of water previously pumped from the surface waters. The idea of supplying the city with the water from the reservoir was abandoned.

The wetlands downstream the reservoir are mostly river fed type of marshes. It means that for their sustainability the regular river water inundations are necessary. The natural, extensive meadows in the upper part of the valley are used by local farmers for hay making and as a pasture. Prior building the reservoir spring floods were unavoidable, so farmers has adapted their practice to this phenomena, which resulted in bio-diversity rich, open spaces habitats of molinia meadows, lowland hay meadows and alkaline fens (all of them recognized by EU Habitat Directive). After constructing the reservoir, there is a constant pressure to go into the more intensive farming, which excludes the presence of the flood pulse. The spring inundation is vitally important for the downstream lying marshes of the Narew National Park.

Looking for the main features of the system it seems that crucial for the water management strategies identifications are: (1) inundation of the river valley between reservoir and Suraż gauge station in order to check, which areas in that part of the valley are sensitive to the water release policy on the reservoir and (2) modification of the inflow characteristics to the Narew National Park during the flooding period in order to check if there is a significant impact of the Siemainowka reservoir on the wetlands located downstream the Suraz gauge station. Modeling efforts were focused on those two phenomena's (Okruszko et al., 2004).

3. Method

The analysis was carried out in the general form of the scenario study, which combined different hydrological conditions during the flood event with different releases police from the reservoir Siemianowka. The output contains the hydrological characteristics of inundated area and the inflow characteristics to the area of NNP. In order to perform this scenario analysis modeling system was constructed. There are five basic components of this system, namely: rule based model of the Siemianowka Reservoir, hydrological model of the Narewka River, hydrological model of the Orlanka River, 1D unsteady state flow routing model and GIS ARCView based platform for linking all models (see Fig. 2).

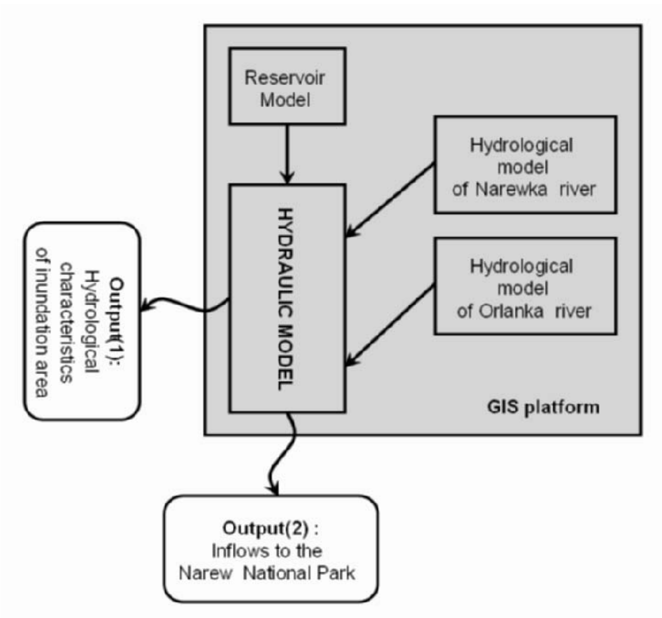


Figure 2. The basic components of the system

Rule based model of the Siemianowka reservoir consists of two, the most popular in Poland release policies i.e.: standard policy and constant safe outflow policy. Both rules are linear, calculating the outflow from the reservoir as a function of inflow and actual state of the reservoir. The model of Siemianowka reservoir explores a mass balance method. The simple hydrological models of the Narewka and Orlanka Rivers (two main tributaries to the Upper Narew River) were based on the results of the gauge station observations in Narewka and Chraboly cross-sections. The gauge station results were transformed to tributaries outflow by adding the subcatchment flow based on aerial, time dependant specific discharges. Hydraulic model bases on a CCHE1D software package for 1-D unsteady state flow in open channel (Weiming, W., Vieira, D.A. 2001). The GIS platform consists of the three different programs, namely: NCCHE 1D, ArcView and PCRaster, which are responsible for data preparation for the hydraulic model and final calculation of the hydrological characteristics of the river valley (Werner et al., 2000). The historical data of flow discharges were used for the CCHE1D model parameters calibration and model performance validation. The ever highest recorded flood of 1979 was used for the model calibration, 24 other flood events of years 1967 - 1988 were used in validation process. The numerical model satisfactorily simulated the measured data.

4. The Upper Narew System Analysis

4.1. DESCRIPTION OF ANALYZED VARIANTS

Variant 0 was modeled, assuming no Siemianowka reservoir. Results of all other variants have been compared with the results of variant 0, assuming that all of them have the similar inaccuracy in simulation the reality. It means that differences in water management strategies are measured using the relative changes between the variants.

Beside the variant “0” four other variants have been calculated. In the variant A reservoir is used for the water supply only. The flood protection rules are not applied. This variant fulfills the basic requirement of ecologist for no active flood protection. In contrary to this variant B is constructed. It assumes that $25 \cdot 10^6$ m^3 of the reservoir volume are used as a flood protection reserve, which is filled in the case the safe flow of 10 m^3/s is exceeded. This release policy meets the requirements of the local water authority standards. The variant C simulates the requirements of the farmers having their fields in the river valley. They are urging for increasing the reservoir volume used for the flood protection as well as decreasing the value of the safe outflow. As a result variant, which assumes the flood protection reserve of $40 \cdot 10^6$ m^3 and safe outflow of 8.6 m^3/s was analyzed.

In the Variant D it is allowed to create the “flood pulse”. In the case when there were no flooding conditions up to the end of April, artificial flood wave of 15 m^3/s is created. All other reservoir release policy parameters are the same as in the variant B.

In all analyzed variants it is assumed that for normal and low flow conditions the standard policy is applied, having 4 m^3/s as a minimum required outflow. This value is a sum of the biological flow and hydropower production by two turbines. The basic parameters of the analyzed variants are presented in Table 1.

TABLE 1. The basic parameters of the analyzed variants

Variants	Total volume [10^6 m^3]	Flood protection storage [10^6 m^3]	Safe outflow [m^3/s]	Basic outflow [m^3/s]	Other [m^3/s]
Variant 0	0	0	-	0	-
Variant A	70	0	-	4	-
Variant B	70	25	10	4	-
Variant C	70	40	8.6	4	-
Variant D	70	0	-	4	pulse 15

In order to compare the variants two basic performance criteria were applied. For the valley between reservoir and the Park frequency of the inundation was used. For the park inflow hydrograph in Suraz was analysed using the reduction ratio of the peak flow and reduction ratio of the flood wave volume.

4.2. RESULTS OF VARIANTS CALCULATION

The initial results confirmed that Siemianowka reservoir is big enough to reduce all historical flood waves to the safe outflow 10 m^3/s or 8.6 m^3/s in the first reach downstream the reservoir.

In the next step for the analyzed region frequency of yearly inundation was compared for each variant. It was assumed that inundation in the particular raster of the area occurs in the given year if at least on one day the water was above the land surface. It means that frequency equal to 0 occurs if there were no inundation for all historical flood waves on contrary frequency 100 means inundation of the raster occurred during each analyzed flood waves. Three regions were chosen for comparison: valley upstream the Narewka River mouth, valley between Narewka and Orlanka Rivers and the valley downstream Orlanka River up to Suraz. Going downstream, each valley segments is more affected by the subcatchment flow. Five specific frequency ranges were chosen for the analysis (Table 2): no flooding at all, rare floods (0.01 to 25%), average flooding (25 to 50%), often floods (50 to 75%) and very often floods (75 to 50%). The two last categories are recognized by the plant ecologist as suitable for wetland plants development, average flooding is suitable for so called wet, extensive meadows. Two remaining categories are only ones suitable for the intensive grasslands.

Results presented in Table 2 confirm that two first reaches of the valley are strongly dependent on the reservoir release during the flooding. Flood defense policy (variants B and C) may increase the surface, which is free of flooding by

TABLE 2. Frequency of inundation in the particular part of the valley

Variant	Region	Inundation frequency in the specific area [ha]				
		0%	0.01-25 %	25-50 %	50-75 %	75-100 %
	Bondary	59.16	79.84	17.8	8.04	191.56
	Downstream Narewka	843.32	952.4	93.64	57.2	433.68
	Downstream Orlanka	582.48	1008.16	231.96	187.88	1138.52
0	**Total**	**1484.96**	**2040.4**	**343.4**	**253.12**	**1763.76**
	Bondary	59.4	87.36	17.08	26.76	165.8
	Downstream Narewka	849.28	974.52	97.04	65.56	393.84
	Downstream Orlanka	626.76	1008.96	251	234.76	1027.52
A	**Total**	**1535.44**	**2070.84**	**365.12**	**327.08**	**1587.16**
	Bondary	156.12	11.6	6.28	14.2	168.2
	Downstream Narewka	1295.04	593.36	53.6	39.68	398.56
	Downstream Orlanka	799.56	949.24	207.4	161.48	1031.32
B	**Total**	**2250.72**	**1554.2**	**267.28**	**215.36**	**1598.08**
	Bondary	160.6	12.24	4.96	6.08	172.52
	Downstream Narewka	1325.44	575.12	49.28	32.24	398.16
	Downstream Orlanka	804.6	965.44	200.12	151.92	1026.92
C	**Total**	**2290.64**	**1552.8**	**254.36**	**190.24**	**1597.6**
	Bondary	59.28	88	16.4	27.6	165.12
	Downstream Narewki	855	971.64	91.8	67.36	394.44
	Downstream Orlanka	606.32	1032.48	247.76	226.76	1035.68
D	**Total**	**1520.6**	**2092.12**	**355.96**	**321.72**	**1595.24**

more then 500 ha in these parts of the valley. At the same time it is very difficult to increase the inundation of wetland places (frequency above 50%) even in the ecological variant D comparing to the "no reservoir" situation.

The impact of the release polices on the Narew National Park was analyzed using a comparison study of the Suraz gauge station hydrograph, which is situated on the inflow to the park.

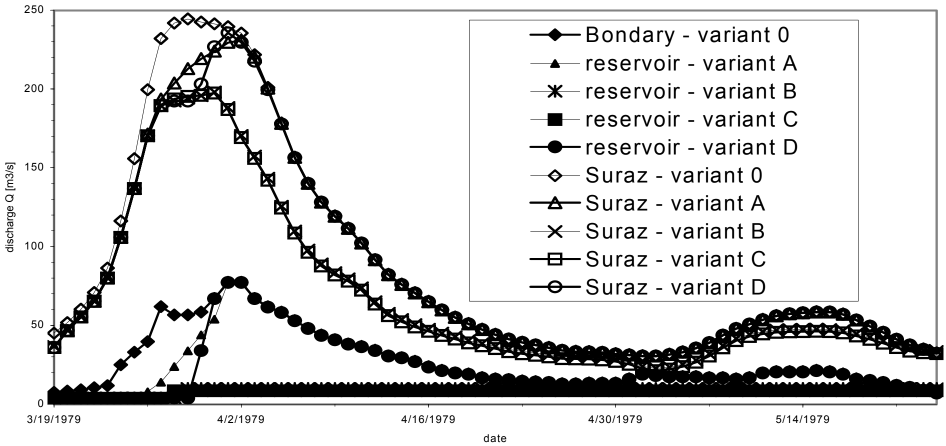


Figure 3. Discharge hydrograph at Suraż for variants with and without Siemianówka reservoir (flood event 1979)

The hydrograph presented in Fig. 3 illustrates the impact of the reservoir on the highest ever recorded flows in the catchment.. In this case, Variant C, which is the most reducing reservoir outflow and discharge at Suraz gauge (Table 6), decreases water level in this cross-section no more then 0.14 m. This value does not have significant impact for a flood extend in area close to Suraz and besides contains in an accuracy (0.35 m) of the valley DEM. There was no relation found between the scale of the flood in Bondary and effctivness of the reservoir policy on Suraz hydrograph. It is casued by high variation of the subcatchment inflow between Bondary and Suraz in each case. The total volume of the flood wave in Suraz sustain in average 30% of volume of Bondary wave, 30% of volume of the Orlanka and the Narewka Rivers flood waves and 40% of direct subcatchment flow. Variation of each component was up to 30% for the particular flood event. As the highest negative impact on the maintenance of wetland ecosystem in the NNP has frequent lack of the flood pulse, the wetland protection release policy should be used for the reservoir control.

5. Conclusions

The results of the calculation using developed modeling system led to the following conclusions:

1. The inundation characteristics of the river valleys allow for identification of the areas, which are the most sensitive to the water reservoir release policy. Those "hot spots" should be analyzed, in the first place, for finding the compromise solution. The ecological values can be protected either by purchasing the land form the farmers or should be subsidized in the frame of the agro-environmental financial schemes of European Union. This compromise should allow for using more ecological friendly release polices, represented in this paper by variants A and D.
2. There is a significant impact of water release policy on the Siemainowka reservoir on inflow to the Narew National Park, as long as the average floods are considered. In order to optimize the release policy of Siemianowka reservoir inflows from the Narewka river and the Orlanka river should be explicit considered.
3. The proposed approach combining the numerical models and the ecological expertise for finding the compromise solution can be applied in other river valley rich in the riparian wetlands. Lack of the data and/or high costs of their getting for calibration of a hydrodynamic model can form the major obstacle in using of this method.

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SALTWATER INTRUSION IN A UNCONFINED COASTAL AQUIFER: THE CASE STUDY OF CERVIA (NORTH ADRIATIC SEA, ITALY)

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Abstract. The coastal freatic aquifer of the Cervia city is polluted by salt water. Protection of fresh groundwater resources in this area is complicated by the presence of multiple stakeholders and by the fragmentation of the authorities responsible for land planning. Most of the topography is under sea level or in its close proximity. Consequently, most of the aquifer does not have a hydraulic head able to prevent the intrusion of the salt wedge at its base (Ghyben-Herzberg principle).Water table and salinity maps show an aquifer almost completely invaded by salt water with bubbles of surface fresh water almost completely confined to elevated areas located near the coast. The study identified as causes of salt water intrusion: direct contamination from canals open to sea, subsidence, drainage of farmland, groundwater extraction from wells along the shoreline (bathing establishments) and, last, groundwater winning from private wells

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inland. On the basis of these results some mitigation action can be proposed: the lining of the salt canals, a different management plan for the floodgates on the canals, to provide shoreline establishments with freshwater from other fresh water resources as a measure to stop direct tapping from the aquifer.

Keywords: Saltwater Intrusion, Unconfined Costal Aquifer

1. Introduction

Coastal aquifers represent a precious resource for the water demand in densely populated areas such as California, Florida, Hawaii, The Netherlands, Thailand and the northern Adriatic Italian coast (Segol et al. 1976, Sonenshein R.S. 1995, Souza W.R. et al. 1987, Konikow L.F. et al. 1999). These aquifers are sensitive to change coast morphology. Coast morphology is related to the natural evolution of the shore environment, which is in a state of continuous change (Carter R.W.G. 1988), and to the man-induced interventions on the territory and on land use. It is therefore apparent, that a inappropriate management of the coastal areas and in particular of the aquifers therein, can lead to the destruction of the fresh groundwater resources at a pace that is much faster than for a regular inland aquifer not connected to sea.

The reason for this high vulnerability stems from the process of salt-water intrusion, which results from the ingression of a high-density salt-water wedge underneath lower density freshwater with an inland origin. A diminished fresh-water hydraulic head or gradient causes the salt-water intrusion. This decrease in hydraulic head can be caused by natural processes such as drought and subsidence or by human activities such as water extraction from wells or land reclamation.

The relationship controlling salt water intrusion is the well-known Ghyben-Herzberg relationship (Fetter 2001) reported below (see also Fig. 1):

$$Z_s = [(\rho_s - \rho_d)/\rho_s] Z_d \quad (1)$$

Where ρ_s is the salt water density, ρ_d is the freshwater density, Z_s is the depth of the salt water/freshwater interface and Z_d is the water table height. From this relationship, we can calculate Z_s, that for typical values of density, is related to Z_d by a factor of 40.

The most common reason for salt-water intrusion in coastal aquifers is intensive or uncontrolled phreatic groundwater extraction via water wells that depress the water table (Bear et al. 1999). Another important cause for coastal aquifer salinization is land subsidence. This is an indirect cause. Land subsidence, in fact, will cause a tendency for the water table to approach the topographic surface. The water table, therefore, needs to be depressed in order to keep plant roots or any man-made structures above the water table. This depression causes a lowering of the hydraulic head and allows for salt-water intrusion. A sustainable and efficient management of freshwater resources in coastal areas is, therefore, becoming a complex endeavor often not in agreement with the local economic development policy. We think, however, that it is in the interest of all stakeholders to adopt measures to protect the fresh groundwater resources or to mitigate the already widespread salt-water contamination in a way to warrant ecosystem diversity and the survival of the pristine coastal vegetation such as the pinewoods living along Cervia's coast.

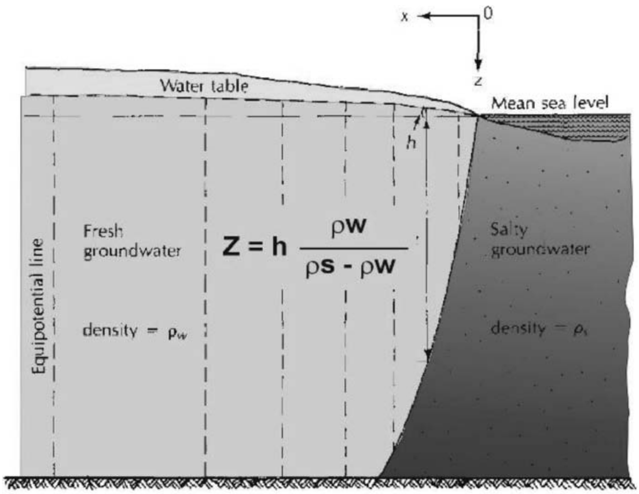

Figure 1. Ghyben-Herzberg relation

These pinewoods have an important historical natural value and they are one of the major attractions for the local tourism industry (GEAprogetti 2001).

The major objective of this study is the characterization of the coastal freatic aquifer in the Cervia municipality. This required an assessment of the extent of salt-water intrusion and to identify the causes that have given rise to the actual polluted conditions starting from a reference "undisturbed" aquifer. What we have learnt is used to propose remedies and protection measures for the fresh groundwater resource.

2. Study Area

The study area includes the coastal phreatic aquifer belonging to the Cervia municipality; the zone investigated has an extension of 20 km^2. The unconfined aquifer has a shaly bottom that is located between 0 meters (inland) and 18 meters (in proximity to the coast). Starting from the 50's, the coastal area underwent an intensive urban development that brought to 50% coverage of the land by buildings and paved surfaces. The remaining territory consists of farmland and pinewood trees that belong to the Regional Park of the Po delta (Fig. 2).

Groundwater extraction from deep confined aquifers and development of offshore gas fields caused a total subsidence of 0.42 meters in the period 1950 – 2004. A dense network of land reclamation drainage canals that is connected to large water scooping machines characterizes the territory. The most important drainage canals are the Scolo Cupa and the Canale Mesola di Montaletto that cuts through the study area and enters the harbor canal of Cervia. The roman age Cervia's saltworks are located 1.5 km inland (Fig. 2). Salt water is brought to the saltworks via the *Canale del Pino*. The harbor canal and the *Canale del Pino* allow for surface salt water intrusion in the area.

We selected 504 water wells in activity within the area investigated; 357 wells have a depth ranging from 3 to 10 m, whereas the other wells have greater

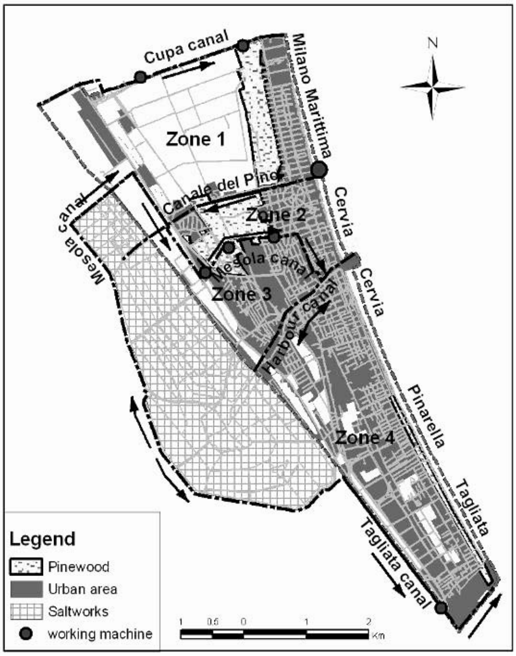

Figure 2. Study area

depth. About half of the wells are used to water gardens and the other half are used to tap freshwater in the beach seaside resorts during the summer period.

We divide the study area in 4 zones:

1. Zone 1: confined by the *Scolo Cupa* in the north Nord and by the *Canale del Pino* in the south;
2. Zone 2: confined by the *Canale del Pino* in the north and by the *Canale Mesola di Montaletto* in the south and in the west;
3. Zone 3: confined by the *Canale Mesola* and by the *Canale del Pino* in the north and by the harbor canal in the south;
4. Zone 4: confined by the harbor canal in the north and by the *Canale Tagliata* in the south.

3. Aquifer Characterization

3.1 AQUIFER LIMITS AND STRATIGRAPHY

The Cervia area is located on a coastal sand dune that was deposited during the marine transgression that took place about 5000-6000 years ago. The marine transgression reached inland as much as 2 km in proximity of *Lido di Savio* and as little as 1 km near the town of Pinarella (Fig. 3). A marsh area developed more inland, to the west, where later the romans established the saltworks.

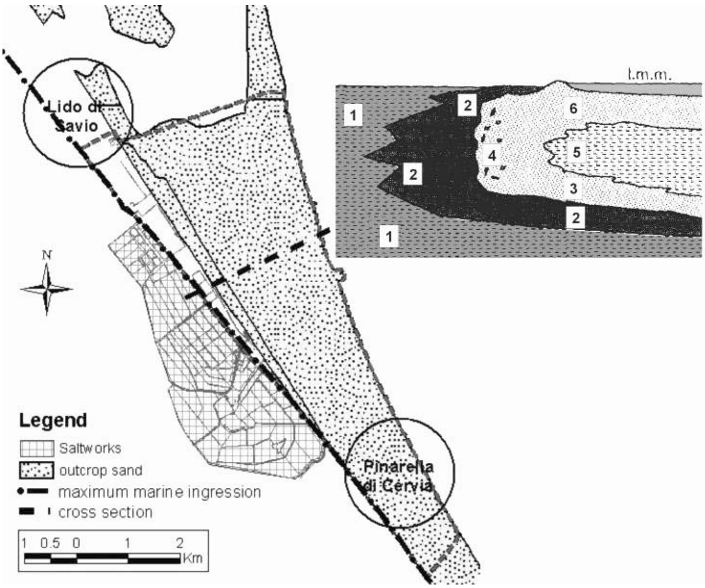

Figure 3. Stratigraphic sequence of the coastal sediments (from Santini, 1992, modif.)

At the same time, clay and silty clays with a river origin were deposited in the marine environment along a belt about 30 km wide (Veggiani 1971). The sand body is delimited in the west by the clay of the lower confining layer that reaches the surface. The confining layer sequence includes tens of meters thick continental and transitional beds deposited during the Wurm glacial period (1-2) (Castiglioni et al. 1990).

Above those deposits, and separated by the Versilian unconformity surface, are found the coastal sandy deposits (3-4-5-6) that were deposited parallel to the coastline during the marine transgression in a wave-dominated environment. These deposits make up the actual coastal aquifer.

The stratigraphic reconstruction of the sequence in the phreatic aquifer was made only in zones 2 and 3 by using 24 borehole records and high quality static penetration tests. Using the granulometric scale Udden-Wentworth normalized the lithologic descriptions. Plotting and data representations have been performed using the Rockworks software and a Geographic Information System.

The aquifer is mostly made up of medium-fine-grained sand with a medium fraction well represented in proximity to coast and a fine fraction represented inland. The sand contains some silty and loamy levels that are more abundant in the central part of the area considered (Fig. 4).

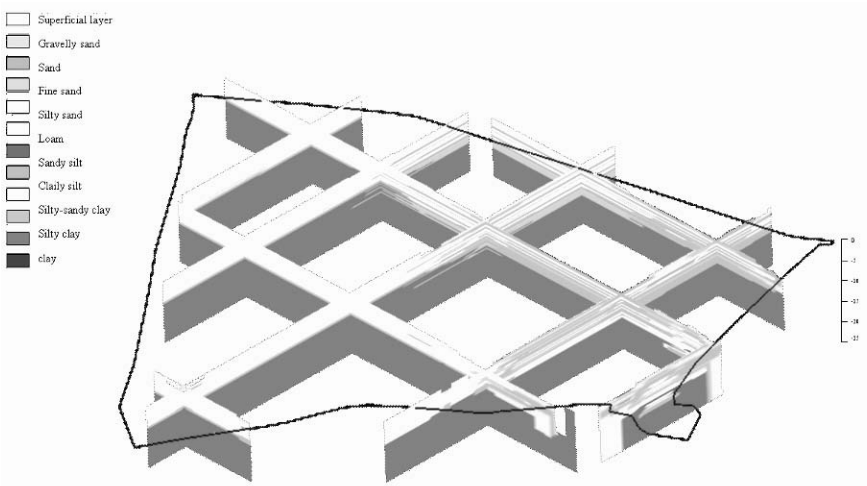

Figure 4. Three-D fence diagram of the lithostrtigrphic sequence in the freatic aquifer

3.2 DATA COLLECTION FOR HYDROLOGIC BALANCE

In order to quantify the rainfall recharging the phreatic aquifer, we computed the hydrologic balance (2). Climate data concerning temperatures and rainfall have been supplied by the meteorological service of the Emilia-Romagna

Region. The other hydrological data were compiled from published data (Geaprogetti 2001).

$$I + Q_{acq} + Q = ET + Q_r + Inf + Q_{idr} + Q_{sea} \quad (2)$$

where:

I = average rainfall (m^3/year)
Q_{acq} = amount of drink-water imported from the aqueduct system (m^3/ year);
Q = water outflow deriving from the river basin drainage that insists on the coastal area, managed in part from the land reclamation authority (m^3/ year);
ET = evapotraspiration (m^3/ year);
Q_r = run-off (m^3/ year);
Inf = infiltration (m^3/ year);
Q_{idr} = stagnating water removed from the Cervia pinewood by drainage systems (m^3/ year);
Q_{sea} = aquifer flow to sea (m^3/ year).

Table 1 shows an estimation of water infiltrated in the ground from hydrologic balance data. The largest infiltration occurs during the winter (20 mm/month), the lowest in the summer where we have a strong infiltration deficit as we would expect from evapotransiration. We have also direct water infiltration from the influence of the canals and imported water from the aqueducts in the coast area (approximately $0.7 \cdot 10^6$ m^3/year).

The outflow to Q_{sea} has been calculated with the Dupuit equation and is about 125 m^3/year, which is negligible in comparison to the other contributions.

TABLE 1. Seasonal hydrolgical balance the entrances for precipitation and the escapes for superficial outflow and evapotraspiration.

Season	Precipitation (m^3)	Run off (m^3)	ET (m^3)	Infiltration (m^3)
Summer	1511400	314468	2440758	-
Autumn	2362714	474871	1312204	522058
Winter	1783368	292282	226206	1231901
Spring	958967	315673	102996	-
			Total	1753958

3.3 FIELD MONITORING

The results of the field monitoring campaign that took place from June 2003 and May 2003 is represented in Fig. 5-6. The monitoring campaign has been done on a total of 187 points (piezometers and canals) and included water table depth, temperature and electric conductivity (converted in salinity values using Lewis e Perkins (1981)equation (Unesco 1983).

The collected data were incorporated into a *GIS* system (Geographic Information System) using ArcGis 8.2. Water table, salinity and temperature maps have been constructed from the data collected. The phreatimetric maps (Fig. 5) show a water talbe depth located a few centimetres above the mean sea level. Consequently, most of the aquifer does not have a hydraulic head prevent the salt water intrusion at its base. The only areas placed above sea level are placed along the coastline and along the present canals (*Canale del Pino*, harbor Channel and *Canale Mesola di Montaletto*), because of their influence on the water table. The water table changes seasonally with a mean range of approximately 0.9 m, with the maximum value of 0.82 m m.s.l. in winter and minimum value in summer of -1.06 m m.s.l.. During the fall-winter season the water table presents more areas above the m.s.l., the result of the greater precipitations and the larger amount of water present in the drainage canals. The surface salinity

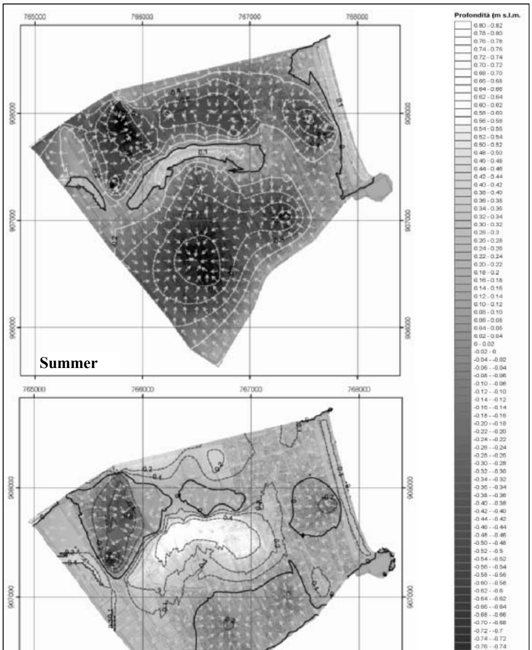

Figure 5. Water table depth maps relatively to the summer and winter period

maps (Fig. 6) demonstrate the salt water intrusion from the harbor canal and the *Canale del Pino*, and is apparent also in proximity to the sea outlets of the drainage canals.

The salinity is also high in proximity to the pinewoods and to the water scooping machines, as consequence of the salt water pull up from the bottom caused by the water table falling due to the pinewood and the waterwork systems.

The salinity value is smaller than 2-3 g/l along the coast line.

On the basis of the water table maps just discussed the salt water – fresh water interface depth was reconstructed with the Ghyben-Herzberg equation on 2 cross section (A e B; Fig. 8). The salt water – fresh water interface does not present the typical shape shown in Fig. 1. It does not reach to bottom confining layer and it does not prevent salt water intrusion in the aquifer.

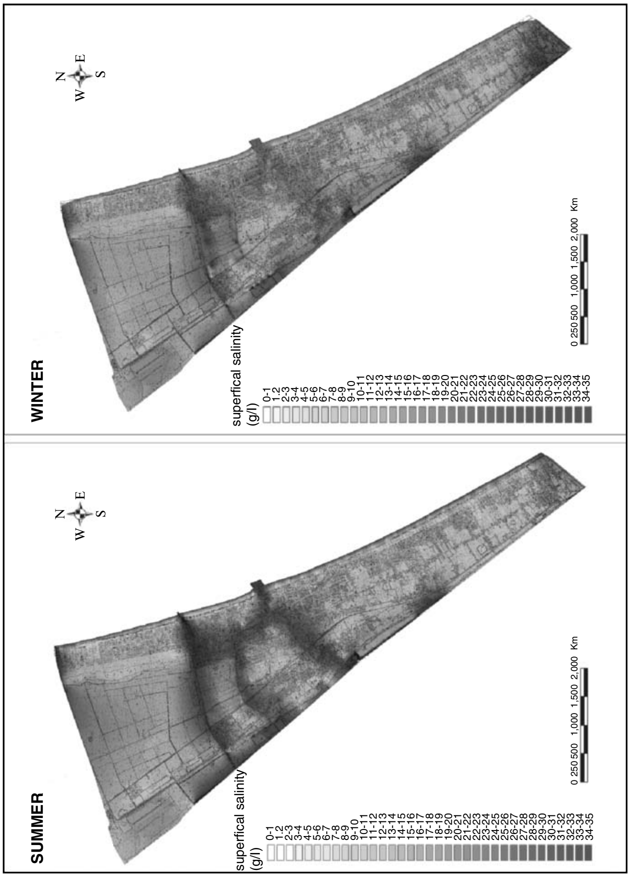

Figure 6. Seasonal surface salinity distribution

Fig. 7 shows the presence of fresh water in the aquifer in the form of bubbles floating over the salt water. The thickness of such bubble changes seasonally as a function of the meteoric contributions and/or of a greater fresh water inflow from the canals.

It is important to emphasize that the interface position in cross section during the summer time shows a high located 80-100 m from the coastline where the wells of the bathing establishments are localized.

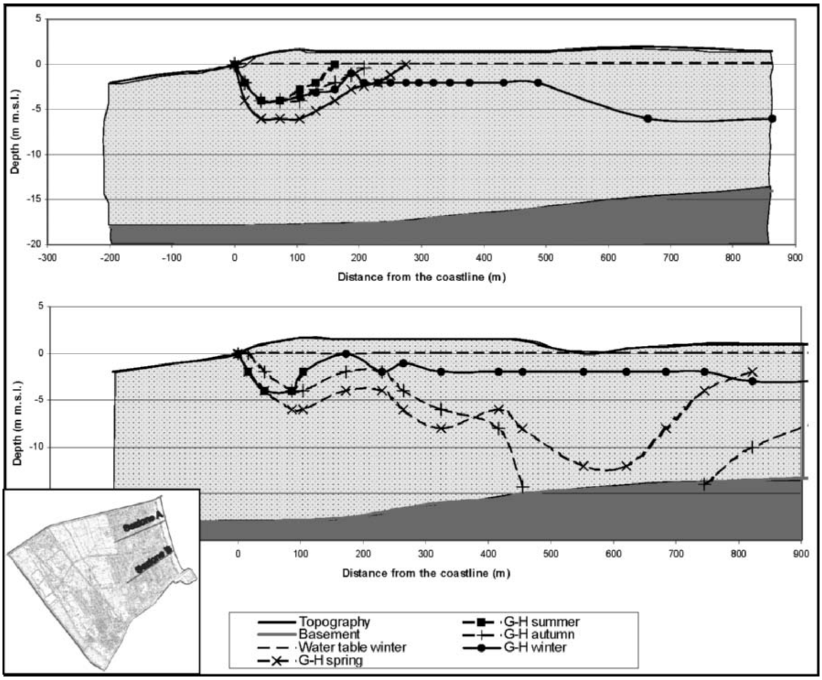

Figure 7. Fresh water – salt water interface calculated using Ghyben-Herzberg law, along the cross sections A and B

4. Aquifer Modeling

The salt-water intrusion that we documented for the present time results from multiple factors such as the influence of the harbor canal and of the *Canale del Pino* (Fig. 2), the land reclamation, the subsidence and the ever growing extension of paved surfaces. Human intervention in this scenario has been so strong in the last one hundred years that it is almost impossible to define the contribution of every single factor in reaching the present condition. For this reason, it is rather challenging to propose some restoration or mitigation actions derive from a “whole system” modeling.

In an attempt to evaluate the weight of every single factor, we reconstructed an "undisturbed" or "less disturbed" condition of the aquifer that represents the starting point of our modeling effort. The year chosen to set our reference state was 1892. At that time the territory was mostly used by farmers to grow corn, there were few scattered houses and the pinewoods had a much larger extension than the one they have at present. The land reclamation area that today extends the (surface) area available for (the) agriculture, at that time (it) was occupied by a marsh (west side of the study area). The *Canale del Pino* did not exist and the salt-water was directed to the saltworks via the harbor canal, that at that time was acting as feeder and discharge channel.

The topographic surface has been reconstructed lifting the territory by the sum of a change in elevation equal to that recorded by the subsidence geodetic network in the period 1950-1999 and of the change in elevation due to the rate of natural subsidence for then modified on the basis the period 1892-1950. The topography obtained was of information collected from historical maps; from this information we have reconstructed the position of the dunes along the coast (some relicts of these still exist today) and the position and extent of the marshes.

The reconstruction of the water table for the year 1892 was derived from the topography with the assumption that the aquifer is completely saturated below sea level. Above sea level, the top of the saturated surface follows the topography, smoothing it.

In order to evaluate the subsidence contribution to the salt water intrusion, an idealized topography has been generated with a phreatic surface lowering of 0.83 m, that represents the subsidence calculated from 1892 to 2003 maintaining the coastline fixed: the basis of this assumption is that the water table level had to be lowered artificially in time to maintain the characteristics of the territory at the year 1892. Due to a lowered water table level, the fresh water – salt water interface is located at a shallower depth (Fig. 8) and is drawn back meeting the clay base at 220 m from the coast line (Fig. 9). The well draw down has been

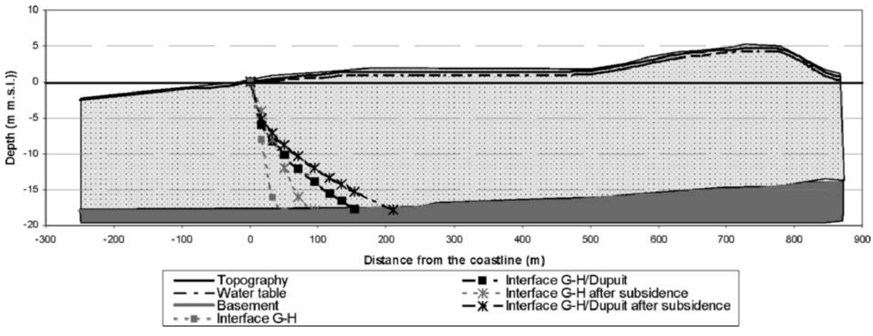

Figure 8. Salt water – fresh water interface in 1892 aquifer

estimated by applying the Strack analytic solution (1976) (Bear et al., 1999) in the case of a well located at a distance of 100 m from the coast line and a pumping rate of 2.3 m^3/day (similar to that estimated in the bathing establishments).

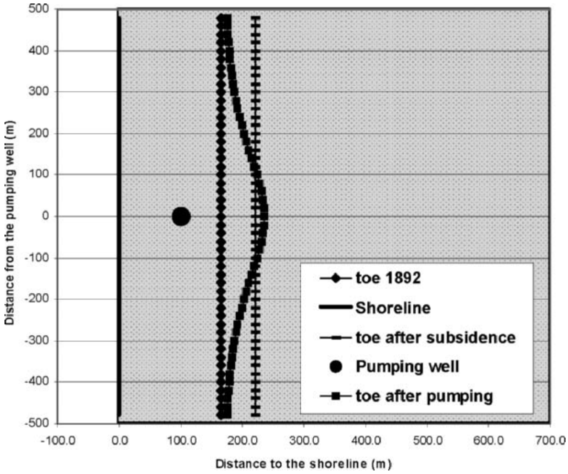

Figure 9. Plan view of salt water – freash water interface

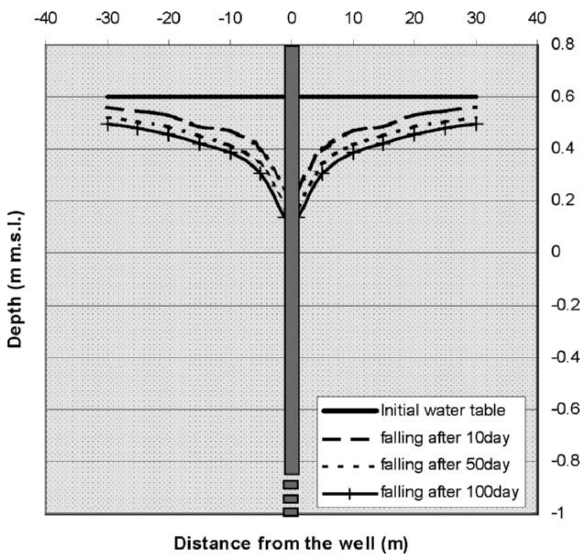

Figure 10. Water table drowdown caused by pumping

The result is a regression of the Xtoe value from the original distance of 163 m to 236 m in proximity to the well (Fig. 9). The Xtoe regression takes place up to a distance of approximately 400 m from the well. Locally, the water extraction determines a draw down around the well that can be quantified with the Neumann's solution (Fetter, 2001). Within one meter from the well, there is a lowering of the water table equal to 0.35 m after 10 days, to 0.43 m after 50 days and to 0.46 m after 100 days (similar to the duration of the bathing season in Cervia) (Fig. 10).

5. Conclusions

Our study demonstrates that the following factors have caused the salinization of the phreatic aquifer:

- Influent behavior of the *Canale del Pi*no and the harbor canal that are losing salt-water to the phreatic aquifer. This behavior is enhanced by the many small drainage canals that allow for salt-water ingression as a function of discharge velocity, meteorological conditions, tidal phase and wave energy;
- Artificial lowering of the water table caused by land reclamation and by water extraction from wells. Subsidence that in this area is caused by deep groundwater and gas extraction, has triggered a process in which it is necessary to lower more and more the water table in order to keep dry the land reclamation areas;
- Urbanization and paving of surfaces that prevent rainwater infiltration to the aquifer.

On the basis of our analysis, we propose some actions aimed to mitigate the problem of salt-water intrusion and to reclaim the aquifer from the actual polluted state.

A first priority would be a *landscape-friendly* lining of the *Canale del Pino* and of the harbor canal in order to stop direct influence of salt-water to the aquifer. This should be done in a way that blends in with the surrounding landscape and is not asthetically. This is important for the local tourism industry.

Another important action would be to prevent water extraction from wells in the phreatic aquifer, given that water can be provided to the citizens in affordable alternative ways.

For this reason, we also propose to connect the shoreline tourism establishments with the municipality aqueduct or with the Emilia-Romagna irrigation canal. The final recommendation of our study is that an integrated management plan for water resources that involves all stakeholders and that is aware of all socio-economic issues in the Cervia area needs to be developed.

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INTERNATIONAL AND INNER TRANSBOUNDARY RIVER BASINS IN THE KALININGRAD OBLAST, SOUTH-EASTERN BALTIC

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Abstract. Present paper gives an overview of transboundary lagoons and river basins in the South-Eastren Baltic, with specific focus on the Vistula Lagoon catchment as a main shared watershed between Kaliningrad Oblast (Russian Federation) and Poland. Management issues for shared river basins in Kaliningrad Oblast are discussed.

Keywords: shared river basins, shared lagoons, transboundary management, GIS analysis

1. Introduction

Most of river basins in the South-Eastern Baltic are transboundary. State borders as well as internal borders between municipalities are not correlated with boundary lines of main watersheds. This non-coincidence of natural and administrative spatial division makes a task of water management in the region rather complicated. Moreover, the countries shared catchments have different management experience and legal basis. Lithuania and Poland as members of European Union are obliged to follow the EU Water Framework Directive, while Kaliningrad Oblast as a part of the Russian Federation uses Russian

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Water Code as a principal law of water usage and protection. In order to approach sustainable management of water resources in the region the joint goals are to be set up. The equal standards in water usage and the comparable procedures of water quality control, water monitoring and management have to be implemented within all shared basins.

The purpose of the present paper it to give an overview of transboundary basins in the South-Eastern Baltic, with specific emphasis of the Vistula Lagoon catchment as a main shared basin between Kaliningrad Oblast (Russian Federation) and Poland.

2. Shared River Basins in the Kaliningtrad Oblast

The main rivers opening in the South-Eastern part of the Baltic Sea are transboundary (Fig.1). The Vistula and Neman (or Nemunas) rivers are the second and forth largest rivers in the Baltic catchment, the Pregolia River may be considered as of intermediate or small scale Baltic river. Their average runoffs are of 33.6, 19.9 (Bergstrom and Carlsson, 1994), and 1.53 (Silich, 1971) km^3 a year respectively. The drainage area of the Vistula River, 193910 km^2 (Voipio, 1981), covers practically total Poland, but includes also relatively small parts of Ukraine (6% of the Vistula catchement) and Belorus (6.5%) (Evaliuation …, 2005). The upper part or 46% of the Neman watershed (the total Neman catchment is of 98200 km^2 (Voipio, 1981)) is in Belarus (Evaliuation …, 2005), the rest is in Lithuania, but downstream part includes Russian territory also, namely, the northern part of the Kaliningrad Oblast. The catchment of the Pregolia River starts in Poland, and, then, covers main part of the Kaliningrad Oblast, Russian Federation (Fig.1).

According to the definition given in the (Convention …, 1992), "transboundary waters" means any surface or ground waters, which mark, cross or are located on boundaries between two or more States …". A river basin is administratively shared if its constituents belong to different administrative units. In case these constituents belong to different countries, the basin will be an international or transboundary river basin. Within one country, a national river basin might be also shared by different municipalities or communes.

One may introduce two principal types (Chubarenko, 2007) of shared river basins. A *shared basin of consequence type* is those, which upper part lays in one administrative unite, while a lower part belongs to another one. If a river passes along the boundary between two administrative units, its basin is considered as *shared river basin of parallel type*, because each side of the basin (left and right) belongs to different administrative units. Very often, a river basin is considered as of mixed type, due to it is partly consequence and partly parallel.

The mentioned above water basins of the Vistula River and the Pregolia River are considered as consequence in general, as basins of their tributaries are of consequence type. In opposite, the lower part of the Neman River catchment is a typical example of transboundary watershed of parallel type, as state border between Lithuania and Kaliningrad Oblast (Russian Federation) passes along the Neman River stream.

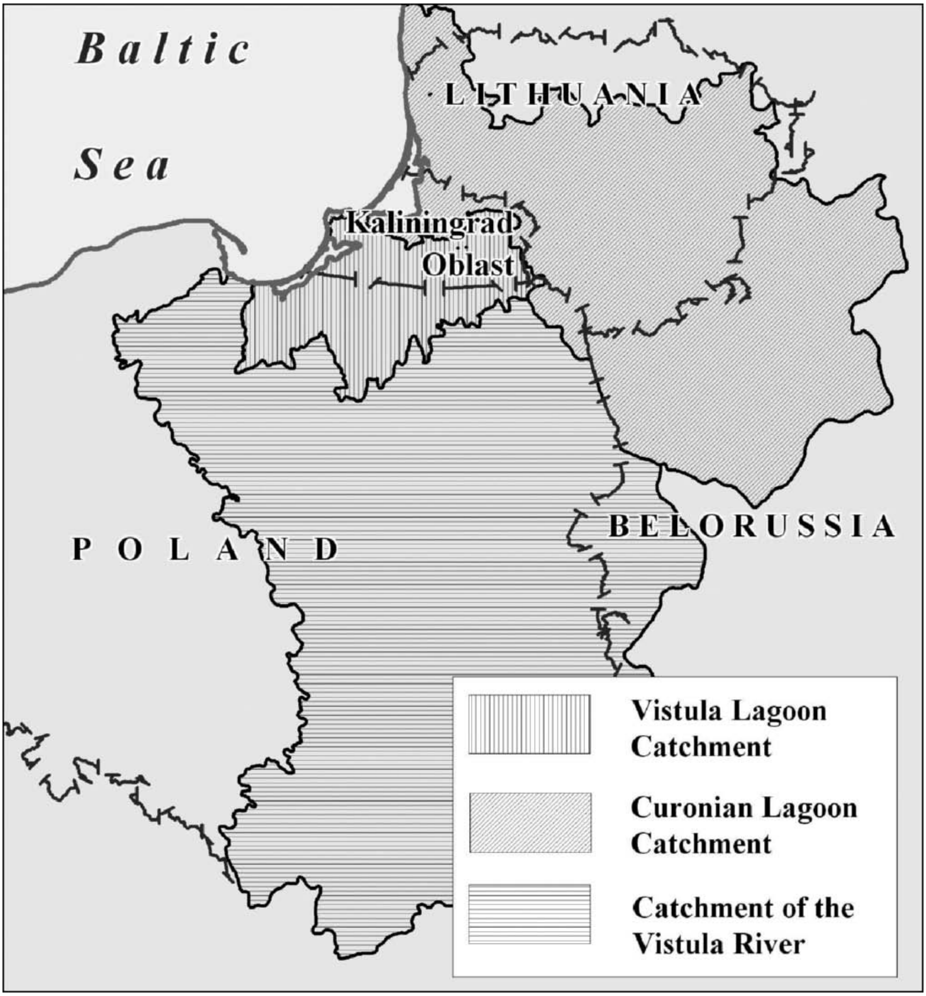

Figure 1. Main transboundary watersheds in the South-Eastern Baltic (from South to North): the Vistula River catchment, the Vistula Lagoon catchment including the Pregolia River and small rivers, the Curonian Lagoon catchment including the Neman River and small rivers

3. Water Management issues for Shared River Basins in the Kaliningrad Oblast

Water quality in the Baltic Sea, especially in its coastal waters, directly depends on economic activity and water usage in its drainage basin. Most of the nutrients entering the Baltic today come from diffusive sources (Veivo, 2004) and especially from agricultural soils, where they were deposited in the past (Raateoja and Pitkanen, 2004) and are still accumulating nowadays.

Kaliningrad Oblast (Fig. 2) is neighbored by EU countries - Poland and Lithuania, where the Water Framework Directive is a main legislation act concerning a surface, ground and coastal waters. In the Russian Federation, the National Water Code plays the same role. These two basic documents are in agreement with each other in general, but have some important differences (Kessler et al., 2006). Therefore, there is a need to harmonize approaches recommended by both documents in the everyday practice of mutual management of the shared river basins.

Figure 2. The Vistula Lagoon catchment

Water usage in different parts of a transboundary basin has to be closely connected. An upper part influences a lower one in terms of water quality. For example, an intensive agriculture at the upper part of a river basin of Lyna-Lava River definitely intensifies eutrophication at the downstream part of this basin. A low quality of water, unattractive view and low transparency of waters, intensive growth of vegetation along a river bank - all these cause a limitation in usage of water for drinking and recreation in the downstream segments of the river.

And, vice versa, an activity in downstream part influences on an upstream one in terms of water quantity. The same example of the Lyna-Lava River - a regulation of the river runoff in the downstream segment without taking into account upstream needs in water consumption may cause problems in upper part of the basin such as lack of water for irrigation and other purposes.

Potentially problematic situation exists for many of the Baltic Sea river basins, because the very lower stream areas of these basins are densely populated and intended to be used for recreation or tourism, while an agriculture is developed in the upstream segments of the catchments. Therefore, a sustainable management is desired to harmonize needs and development plans for these basins.

4. Transboundary Lagoons and River Basins of the Kaliningrad Oblast

All main water systems of the Kaliningrad Oblast are transboundary. These are the coastal waters of the Baltic Sea, the Vistula Lagoon watershed and the Curonian Lagoon watershed.

The Vistula Lagoon is classified as low salinity non-tidal estuarine lagoon (Chubarenko et al., 2005) and itself is a transboundary water body (Fig. 2). Its volume and area equal to 2.3 km^3 and 838 km^2 respectively, 64% of lagoon volume (1.472 km^3) and 56.4% (472.5 km^2) of lagoon water area belong to Kaliningrad Oblast (Russian Federation), the rest belongs to Poland (Solovjev, 1971). As, the Baliysk Strait, the single lagoon inlet connecting the lagoon with the Baltic Sea, is situated on Russian territory, the Kaliningrad Oblast formally is responsible for the quality of waters coming into the Baltic Sea from the lagoon.

The Vistula and Curonian Lagoons watersheds are connected by the Deima River. As an arm of the Pregolia River, Deima outflows from main Pregolia stream at the City of Gvardeysk and connects Pregolia with the Curonian Lagoon. This means an overlapping of the watersheds of both the Vistula Lagoon and Curonian Lagoon. Approximately 34% of the Pregolia runoff in average is turning toward the Curonian Lagoon through the Deima River (Silich, 1971). Thus, the watershed of the Pregolia River above the City of Gvardeysk, including transboundary watersheds of the Lyna-Lava, Angrapa-Wangorapa and Pissa (13690 km^2 in total), belongs to catchments of the Vistula and Curonian lagoons. This overlapping of watersheds of two Baltic lagoons usually not considered (Markova and Nechai, 1960) and the whole of Pregolia River catchment is attributed to the Vistula Lagoon watershed (Silich, 1971). The only watershed of the Deima River itself and, of course, the total runoff from Deima are attributed to the Curonian Lagoon (Kucheriavyi, 2002).

Northern part of the Kaliningrad Oblast (31.5% of its area) belongs to transboundary water basin of the Curonian Lagoon. The lagoon is a recipient water body for the transboundary Neman River as well as for other small rivers, which watersheds are completely inside the areas of Kaliningrad Oblast or Lithuania. The Neman River starts in the Republic of Belarus, crosses the Lithuania, and then divides the Lithuania and Kaliningrad Oblast. The state border is passing along the lower segment of the Neman River, and Kaliningrad and Lithuanian territories are located on the left and right sides of the catchment (Fig. 2).

The Sheshupe River, the main tributary of the Neman at the downstream part, is also a transboundary river. The runoff of Sheshupe is of 1.12 km^3 y^{-1}. The watershed of the Sheshupe is partly consequence and partly parallel. The Sheshupe starts in Poland, then flows as a border stream, first, between Poland and Lithuania, and, then, between Lithuania and Kaliningrad Oblast. Finally, it crosses the Oblast and merges the Neman River from the Oblast's side.

The southern part of the Neman River delta as well as southern half of the Curonian Lagoon belong to the Kaliningrad Oblast. All waters from the transboundary Curonian Lagoon discharge to the Baltic Sea through the Klaipeda strait on the Lithuanian territory.

5. The Vistula Lagoon Transboundary Watershed

The Vistula Lagoon is a typical estuarine non-tidal boreal lagoon. Its catchment comprises from catchments of main rivers (Table 1) and small streams between them. The Nogat River was the main stream in the catchment before 1916. Being a branch of the Vistula River it brought of 2200 m^3s^{-1} during spring flood (Vypyh et al., 1971), that is approximately of 20 times high then nowadays spring flood of the Pregolia River. The runoff from the Nogat was practically cut during regulations in 1916, when a whole of the Vistula River runoff was directed toward the Baltic Sea. Since that, the Pregolia River became the biggest river in the Vistula Lagoon catchment.

TABLE 1. Main rivers of the Vistula Lagoon catchment (Silich, 1971).

River name	Where does inflow in the Lagoon?	Runoff, $km^3 y^{-1}$	Watershed area, km^2
The Pregolia River (transboundary)	Russian part	1.5265	15500
The Paslenka River (Poland)	Polish part	0.5030	2329
The Prokhladnaya River (transboundary)	Russian part	0.2717	1170
The Elblag (Poland)	Polish part	0.2312	1488
The Bauda River (Poland)	Polish part	0.0919	361.1
The Mamonovka River (transboundary)	Russian part	0.0747	311
The Nelma River (Kaliningrad Oblast)	Russian part	0.0443	167
The Nogat River and 'zhulavy' (Poland)	Polish part	0.6623	1336.9
The Shkarpava River (Poland)	Polish part	0.1010	807.9

TABLE 2. Main rivers of the Pregel River catchment, and national shares of their runoff (Silich, 1971), watershed areas and length of stream (Igoshina, 2002).

River name and where it does inflow in the recipient pool or stream? All parameters are given for this point of river inflow.	Runoff , $km^3 y^{-1}$	'Kaliningrad Oblast' + 'Poland' = 'Total'	
		Watershed, km^2	Stream, km
The Pregolia River itself (from the Cherniakhovsk to the Vistula Lagoon), it inflows in the Vistula Lagoon downstream of the Kaliningrad	1.53	7100 + 8400 = 15500	123 + 0 = 123
The Deima River inflows into the Curonian Lagoon, it outflows from the Pregel River approximately at 45 km upstream the Pregel mouth	0.93	313 + 0 = 313	37 + 0 = 37
The Lyna-Lava River inflows into the Pregel River at 72 km upstream its mouth	1.36	1370 + 5750 = 7120	65 + 224 = 289
The Golubaya River inflows into the Pregel River at 102 km upstream its mouth	0.12	564 + 0 = 564	59 + 0 = 59
The Instruch River inflows into the Pregel River at 123 km upstream its mouth	0.26	1250 + 0 = 1250	101 + 0 = 101
The Angrapa River inflows into the Pregel River at 123 km upstream its mouth	0.80	610 + 1910 = 2520	97 + 72 = 169
The Pissa River inflows into the Angrapa River at 8 km upstream the point where the Angrapa River meets the Pregel River	0.29	930 + 240 + 90 (Lithuania) = 1280	99 + 5 (Lithuania) = 104

The Vistula River runoff was a main source of water and sediment gain for the Vistula Lagoon and even gave a name to the lagoon. The closing of the Nogat branch of the Vistula delta started new phase of the Vistula Lagoon evolution at the beginning of the XX century. After that the lagoon, which was before as fresh as the Curonian Lagoon, very quickly became a water pool of intermediate salinity (3-5 psu). New regimen in a water balance brings dramatic changes in the lagoon ecosystem and sediment balances. Discharge of sediments towards the adjacent sea area prevailed the sediment accumulation rate in the lagoon (Chubarenko and Chubarenko, 2001).

The whole area of the Vistula Lagoon drainage basin equals 23871 km^2, 60.8% of it is in Poland, 38.9% - is in Kaliningrad Oblast and 0.3% is in Lithuania (Silich, 1971). The basin is formed by catchments of the Pregolia River and its tributaries (Instruch, Lyna-Lava, Angrapa-Wangorapa, Pissa, Golubaya) and some other small rivers (see Table 2).

The watershed of the Vistula Lagoon is a transboundary one of consequence-parallel type (Fig. 3). Both national parts of the lagoon have their own drainage basins. One may select only those sub-catchments of national drainage basins, which are entirely within national territories. These sub-catchments form a 'parallel' part of the lagoon drainage basin, as they independently contribute water into the lagoon volume collecting runoffs from national territories only (Tables 3 and 4). The area of 'parallel' part of the Vistula Lagoon drainage basin equals of 35% of its total value, the runoff from it equals of 1.894 km^3y^{-1} or 40.2% of total river runoff to the lagoon. The Nogat, Pasleka, Bauda, Elblag and Szkarpawa rivers comprise a Polish national share in this 'parallel' part. This share equals to of 27.8% of the total Vistula Lagoon drainage basin. It supplies of 33.6% of total river runoff to the lagoon. The Primorskaya and

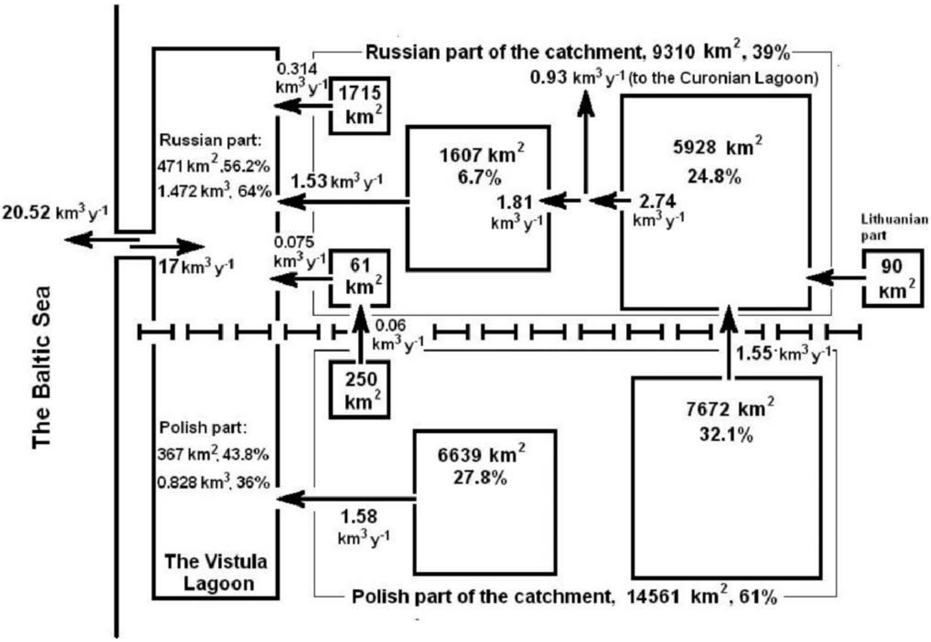

Figure 3. Principal hydrographic scheme of the Vistula Lagoon catchment

Nelma as well as other small streams entering the Vistula Lagoon in the north form the Russian 'parallel' part of the drainage basin (7.2% of area and 6.7% of runoff).

TABLE 3. National shares of the Vistula Lagoon (VL) and its catchment.

National shares:	Russian		Polish		Lithuanian		Total for VL	
	Value	%	Value	%	Value	%	Value	%
VL volume (km^3)	1.472	64	0.828	36	0	0.0	2.3	100
VL area (km^2)	471	56	367	44	0	0.0	838	100
VL catchment (km^2)	9310	39	14561	61	90	0.4	23961	100
Parallel (independent) part of the VL catchment (km^2)	1715	7	6639	28	0	0.0	8354	35
Consequently shared part of the catchment (km^2):	7595	32	7922	33	90	0.4	15607	65
- the Pregel River catchment	7534	31 4	7672	32	90	0.4	15296	64
- the Mamonovka and Prokhladnaya catchments	61	0.3	250	1.0	0	0.0	311	1

TABLE 4. Shares of the runoff in transboundary Vistula Lagoon (VL) catchment.

Shares:	Russian share		Polish share		To Curonian Lagoon		Total to the Vistula Lagoon	
	km^{3}y^{-1}	%	km^{3}y^{-1}	%	Km^{3}y^{-1}	%	km^{3}y^{-1}	%
Runoff from the VL catchment,	1.519	32.3	3.19	67.7	0	0.0	4.709	100.0
Runoff from parallel parts of the catchment	0.314	6.7	1.58	33.6	0	0.0	1.894	40.2
Runoff from consequently shared parts of catchment:	1.205	25.6	1.61	34.2	0.93	19.7	1.885	40.0
- runoff from the Pregel River catchment (above Gvardeysk)	1.19	25.3	1.55	32.9	0.93	19.7	1.81	38.4
- runoff from Mamonovka and Prokhladnaya catchments	0.015	0.3	0.06	1.3	0	0.0	0.075	1.6

In addition, the Russian part of the lagoon watershed contains three transboundary rivers having catchments of 'consequence' type, i.e. the upper parts of their catchments belong to Poland (and Lithuania), while lowstream parts belong to Kaliningrad Oblast. These are the Pregolia River, the main river of the Vistula Lagoon catchment, which brings to the lagoon of 43.7% of total river runoff, and two small rivers – Prokhladnya and Mamonovka, which together bring of 2.1% of total river runoff to the lagoon (Silich, 1971)

This ‘consequence’ part of the Visula Lagoon watershed comprises 65% of the total lagoon watershed. It starts in Poland (33.2%), and the rest (31.8%) belongs to the Kaliningrad Oblast. It consists from two independent parts. The smaller one is formed by catchments of Prokhladnya and Mamonovka rivers and equals to 1.4% of total Vistula Lagoon watershed. The biggest one (63.6% of the lagoon watershed) is formed by transboundary basins of Lyna-Lava and Angrapa-Wangorapa rivers (both are 55.8% of the lagoon watershed) and a catchment of main stream of the Pregolia River passing across the Kaliningrad Oblast. A small part of the lagoon basin (90 km2 or 0.4%) belongs to watershed of the Lake Wystynets in the Lithuania.

6. Concluding Remarks

Water resources of the South-Eatsren Baltic are essentially transboundary. They are shared by Kaliningrad Oblast, Lithuania and Poland, which have different legal systems for water issues. This is an obstacle for rapid development of common goals and standards for any given water basin. But, from other side, this is a great challenge and driving force for an international cooperation towards really sustainable development of water resources in the region. As resources are shared all stakeholders have to feel a responsibility for sustainable use of these resources. The stakeholders have to remember that they are neighbors within a basin, therefore they depend upon each other.

Only few steps toward harmonization of regulation as well as monitoring programs and other tools supporting decision making process were made in the region (Rassmussen, 1997; ENVRUS, 9803, MANTRA, 2004). More deep efforts of harmonization are to be done, and, first of all, elaboration of the joint river basin management plans for the main transboundary watersheds.

Catchments boundaries don’t coincide with national borders as well as with internal boundaries between municipalities or other administrative units in Kaliningrad Oblast, Lithuania and Poland. This mismatching is a basis for scaling of transboundary issues within the countries (Chubarenko, Domnin, 2007). National municipalities (as well as countries) have to coordinate their activities in order not to limit their neighbors in water consumption (Fig. 4).

The detailed analysis reveals the rather complicated structure of the transboundary Vistula Lagoon watershed (Poland - Russia). The Vistula Lagoon itself is shared by Poland and Russia. The Vistula Lagoon watershed is shared also by these countries, but a small part is in Lithuania. The Vistula Lagoon watershed has two ‘parallel’ national segments, which supply water in the lagoon independently, and the ‘consequence’ part, upstream segment of which is in Poland and a lowstream one is in the Kaliningrad Oblast. Part of a runoff from this consequence part never riches the Vistula Lagoon, as it is flowing towards the Curonian Lagoon through the Deima River branch. Geographical structure of water fluxes in the Vistula Lagoon transboundary watershed is so complicated that their prediction as well as an assessment of natural responses on a human impacts are possible only using a numerical model.

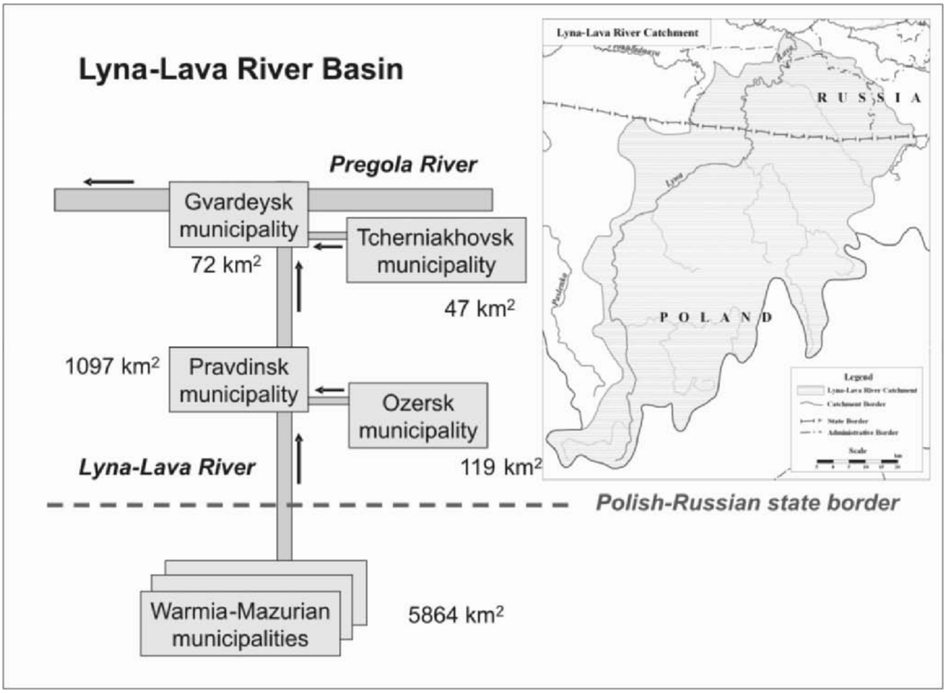

Figure 4. Municipalities in the Lyna-Lava River basin (Chubarenko, Domnin, 2006)

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PART III

REPORTS OF THE WORKING GROUPS

ENVIRONMENTAL INDICATORS FOR WATER RESOURCES MANAGEMENT

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Abstract. Water is a vital substance, essential for most life processes and as a liquid flow resource is the connector of all components of ecological and life systems. It is the environmental integrator. As a resource, water is both a natural component of nature and a commodity, or resource, that may be used by people for the benefit of society. This use is called management. Water has inherent characteristics that allow it to maintain processes and thus provide services;this inherent character is called the carrying capacity. Examples of carrying capacity may be waters ability to assimilate wastes, or dissipate excessive heat, or support a given amount of life. If the effects of such activities become large in magnitude and exceed the carrying capacity of water, it becomes srtessed and its capabilities to provide the services may cease.If ecosystems become stressed and impaired those that are dependent on ecosystems likewise become stressed, including human beings. As the liquid that connects all components of ecosystem there are symptoms, called environmental indicators, that may be used to assess the stress level of water; much like there are indicators that are employed to assess stress levels in human systems, e,g, pH, content of chemicals,presence of microbes. Indicators must represent or be correlated with effects of management. In addition these indicators must be relevant, acceptable, measurable, timely and sensitve. To asses effects of management and potential irreversible impact on water systems some reference for comparison is most helpful. One approach in

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flow water systems is the “input-output” model. Here an indicator is chosen and measured prior to an activity and measured again following the activity; this provides an index of impact and degree of stress.

Keywords: environment; indicators; carrying capacity; water resources management

1. Introduction

Water, like air, is essential for life by both ecosystems and humans. They are commonly termed resources and are often included with other natural resources such as soil, minerals, fauna and flora. This is both useful, as it indicates that all components of the natural world (the physical environment) are connected and dependent, and also unfortunate in that we believe we can manage water like we do soil, fauna and flora. Water (and air) is a flow-resource. Water is one of the natural resources, like solar energy and air, without which there is no human existence! Humans can do little to manage air or solar energy; yes humans can modify the quality of air and solar energy but with minimum effectiveness. They can manage water!

Water is an unique substance in its role on Earth; chemically, physically and biologically. It is the substance that connects and integrates the ecological components of ecosystems and it is the medium within which biochemical and physical processes occur. This facilitates life through maintaining ecological function. Ecological function sustains life through the photosynthetic process and the resultant trophic levels of life, that function as a result of respiration, and thus provides human life necessities, such as food and shelter. Ecological function also provides environmental services that sustain a living Earth. Earth’s processes, including ecological processes, are cyclical, with no beginning or end. Work that is done by ecological processes e.g. production of food and fibre, is possible only by the availability of the ingredients (natural resources) provided by Nature and the constant solar radiation that energies the thermodynamic system. This process results in both desirable products and wastes, from the human perspective. This is shown by the following:

Photosynthesis: Energy + carbon dioxide + water gives carbohydrate + oxygen + heat (waste)

Respiration: Carbohydrates + oxygen gives biological energy (ATP) carbon dioxide and heat (waste)

There are no “wastes” in ecological systems! The wastes of our process are the ingredients (resources) of the next phase of the continuous ecological cycle.

2. Ecological Carrying Capacity

This discussion leads to the conceptualization of ecological carrying capacity. If one accepts that at any place on Earth, the amount of solar energy per unit area, per unit time is fixed, and that there is an atmospheric circulation pattern that sustains a steady state among the atmospheric gasses, notably oxygen and carbon dioxide, the limiting factor for the production of biota through photosynthesis is water. To sustain life requires respiration. Thus to sustain the cycle of photosynthesis and respiration the essential ecological processes, it is water that is the principal component. We can therefore, for any geographical area, a watershed, a basin, a river or a lake, define an ecological carrying capacity – the amount and intensity of use that can be achieved without degrading the environment's ability to continue to function for that use.

Water is thus essential for life, both to sustain ecological processes and to provide the essential "food" that allows organisms to exist. It is also the fluid within which processes (biological and chemical and physical) occur. It may be considered the "blood" of ecosystems. The inter-connectedness of water among ecological components, its reactions with atmospheric ingredients and solar energy, provides the components for the conceptualization of the hydrologic cycle – a useful mental conceptual model. The hydrologic cycle is the continuum of precipitation, infiltration, percolation, evaporation, evapotranspiration, leaching, drainage, recharge of groundwater, streams, rivers, lakes and oceans and the evaporation of exposed water bodies to evaporation and precipitation – a cycle. Humans can modify the cycle. They do so to enhance societal needs, wants and desires. These activities of management may impair the amount (quantity) or the quality of water, to sustain its pivotal role in ecological processes. Often the effects of human activities are not known and unexpected results come as surprises e.g. algal blooms, life-less (dead) estuaries. In such cases both ecosystems and human systems become stressed! And, if there is no remedial action, stress leads to dysfunction and collapse. Figure 1 illustrates the interconnectedness of water to both ecosystems and human systems.

3. Environmental Services

The term environment includes natural ecosystems as well as human constructed concepts and conditions, such as health, social capital and managed systems. The environment, as a whole provides goods and services that are important or essential for human survival. In economic terms, the environment provides goods and services that first allow ecosystems to function and second, to provide humans with the commodities they need, such as food, forests and, of course adequate

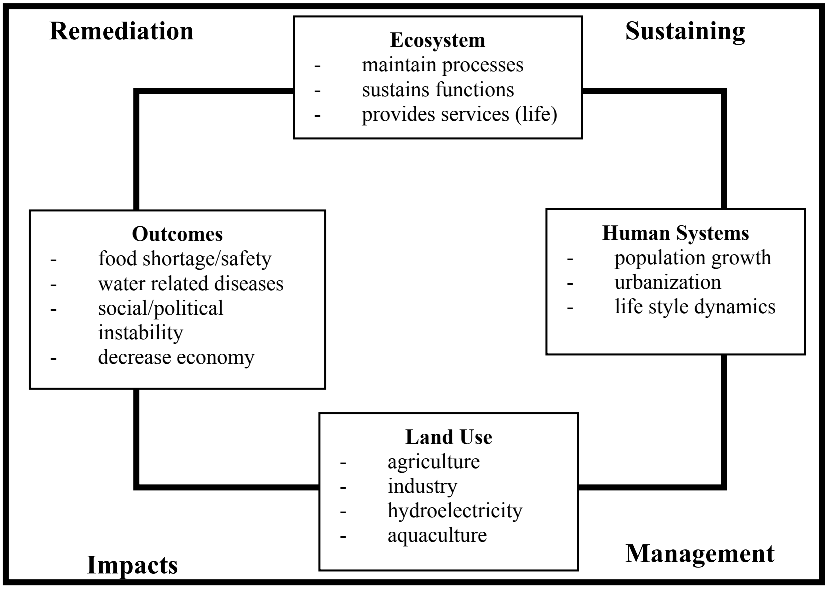

Figure 1. The Relations of Water in Providing Ecosystem and Human System Services

water of the desirable quality. To sustain the environment so that both natural and human made systems continue to provide goods and services, ecological structure and function must be maintained. This is considered a healthy ecosystem!

If we wish to maintain a healthy human community we need to maintain a healthy ecosystem. If human activities exceed natural thresholds of the ecosystem (structure and function, or carrying capacity), for example exceedence of the assimilative capacity of a water system to added biological wastes, or metals, the ecosystem shifts to a new structure and function (i.e. biodegradation is altered and the original ecosystem may collapse) one that is usually less desirable than the original. If such occurs, obviously life forms, including humans, will be affected adversely. Thus, the conceptual and real linkage of ecosystems and human health.

Since water links all components of an ecosystem and is essential for human life and activity, it is the most critical ecological component that humans manage and thus the need to be concerned.

4. Water Scarcity

Concern about water scarcity (quantity and quality) has focused modern society to increasingly turn to technology and economics to address the so-called “water-crisis”, that is the amount of high quality water available to sustain life (including human life!). The first International Conference, to address this issue was held in 1977 by the United Nations in Mar del Plata in Argentina. Others followed in 1990 and 1992. The 1992 Dublin Conference developed the Dublin Water Principles:

1. Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment;
2. Water development and management should be based on a participatory approach involving users, planners, and policy makers at all levels;
3. Women play a central part in the provision, management and safeguarding of water; and
4. Water has an economic value in all its uses and should be recognized as an economic good (commodity).

In 1998, the Secretary, General of the U.N. stated "The assessment (of a 1997 report) concludes that water shortages and pollution are causing widespread public health problems, limiting economic and agricultural development, and harming a wide range of ecosystems. Those problems may threaten global food supplies and lead to economic stagnation in many areas of the world. The result could be a series of local and regional water crises, with serious global implications" (Shiklomanov, 1997).

Subsequent Conferences expanded on the four Dublin Principles and the statements by the U.N. Secretary-General. (See, for example Ministerial Declaration; The Bonn Keys – Bonn Recommendations for Action, International Conference on Freshwater, Bonn 2001 http://www.water-2001de.

Making principles a reality is not an easy task. Serageldin (1994) estimated that it would cost the U.K. close to US $60 billion to build waste water treatment plants to meet the new European water quality standards, or US $35 billion to connect all its citizens to wastewater treatment plants (Gazdag and Remal, 1998) and in the lesser developed countries, the World Bank estimates that over the next decade between US $600 billion to US $800 billion will be needed to meet demands for fresh water and power generation (Serageldin, 1995).

These economic estimates do not consider the political realities of water resource management. Watershed (water basins) boundaries do not recognize political or national boundaries or borders. Water management strategies must help countries that share river basins develop feasible policies to manage water resources more equitably. Nearly 100 countries share about 13 rivers and lakes and more that 200 rivers cross international boundaries (Postel, 1997; Wallensteam and Swain, 1997). Conflicts can arise, as water-short countries are inherently unstable.

5. Services Provided by Freshwater Systems

The human enterprise is dependent on high quality and available water. Freshwater ecosystems and watersheds provide a variety of fundamental functions. These include:

- provision of adequate quantity and quality of water
- a variety of organisms (biodiversity) that purify waters and may be used as food for people and wildlife
- filtering and biodegrading human wastes and contaminants
- maintaining soil fertility, and help regulate floods by watersheds
- provision of habitat for wildlife species
- provision of nutrients and sediments to deltas and estuaries
- buffering salinity gradients of deltas/estuaries and coastal marine communities, and
- provision of scenic, cultural and spiritual values.
- Human activity has modified greatly these environmental services by converting land to agriculture, exceeding the assimilative capacity of aquatic systems to organic wastes, contaminating water systems with metals and radioactive materials, by over-extracting water, thus diminishing biodiversity and by the building of dams that impact the entire hydrologic cycle.

6. Human Health Impacts

Although the links between human activities and water scarcity (in terms of quantity for human use) have been well documented, the link between water management and human health has been recognized only recently. Is there a link between ecosystem health and human health?

Some human health impacts of poor water quality are obvious. These include the worldwide diseases, or disorders, of amoebic dysentery, bacillary dysentery, diarrhea, cholera and of course, metal and radioisotope poisoning. There are several more water vector related diseases such as malaria, dengue and ascariasis. Most, if not all of these disorders are the result of contamination from poor sanitation, causing outbreaks of E.coli, cryptosporidium and giardia. There is increasing evidence that commonly used pesticides and their degradation products are causing health concerns including both incidences of cancer risk and endocrine disruption. Thus many authors mow define water scarcity not by volume of water available per capita, but amount of “safe” water available per capita. Johnson et al. (1998) state that contamination by urban agricultural and industrial activity has resulted in the denial of water to 3.3 billion people.

7. Ecosystem Health

A healthy ecosystem may be defined in terms of (a) vigour, (b) resilience, and (c) organization (Rapport, 2000), and in terms of human society, a healthy ecosystem is one that provides services supportive of human needs; such as food, fibre, capacity to assimilate and recycle wastes, potable water and air.

Vigour refers to energy, which in ecosystems is measured usually by productivity. This is often difficult to estimate but may be approximated by biological productivity in watersheds of aquatic species. Usually the more stress on an ecosystem the less vigour.

Resilience is the capacity of a system to cope with stress. Just as in human health, tests for cardiovascular or respiratory functions are used as an index or indicator of stress, monitoring aqueous systems for parameters, such as pH or oxygen tension, that may be correlated to resilience and to stress.

Organization refers to ecosystem complexity. Stressed ecosystems generally show reduced species richness, fewer symbiotic relationships and more opportunistic organisms.

Since ecosystems are complex, human interactions and needs numerous and both ecosystems and human systems dynamic, the exponential combination of interactions becomes incomprehensible. This has lead to the identification of indicators.

8. Environmental Indicators

Environmental indicators of possible safe water available per capita and indicators that are significant to both human consumption and maintenance of ecological processes, must be representative, recognizable, measurable, and have a scientific basis for consideration. Broad categories of indicators include:

8.1. PHYSICAL

Although these change over space and time, physical characteristics influence how water flows through a system and how this flow is affected by, and in turn affects, adjacent terrestrial habitats. Thus physical characteristics may be measured to (a) assess aquatic system boundaries that affect use and management within the water basin, and (b) assess adjacent to the water body, habitat modification: (Rosgen, 1994).

Factors include:

- Width and depth
- Velocity/flow
- Channel shape
- Channel material roughness
- Sediment load
- Sediment size
- Temperature
- Turbidity

Interpretation of results of these indicators usually depends on some standard condition to which monitoring results can be related.

8.2. CHEMICAL

These indicators are selected to provide information on biological processes or indicators of toxins. They include:

- Oxygen supply (dissolved oxygen or oxygen demand)
- Ionic strength (pH, salinity, acid neutralization, conductivity, total dissolved solids)
- Nutrients (nitrogen, phosphorous)
- Harmful chemical (organics, radioactive heavy metals)

Interpretations of measurements involve comparison to water quality criteria and standards. Since criteria and standards are not known completely nor do we understand cumulative effects, chemical indicators are such – indicators, and need to be combined with other sources of information.

8.3. BIOLOGICAL

Biological indicators assessing numbers, vigor, function and life cycle of organisms are integrators of many physical and chemical characteristics of aqueous systems. Common biological indicators include:

- Macroinvertebrates (insects, worms, mollusks)
- Fish
- Microorganisms (E.coli)

- Phytoplankton
- Periphyton
- Aquatic plants
- Zooplankton

In the interpretation of biological indicators, it is important to conduct bioassay tests to determine unwanted or deleterious effects. This usually involves laboratory tests and comparing "toxin" and "placebo" effects. Decomposition and productivity rate measurements may also be used as in integrative biological indicator of ecosystem (water health).

Interpretation needs to be based on established criteria, and often geographically specific, that has been acquired by scientific referencing. Upstream-downstream gradient analysis has been shown to provide useful comparative data.

8.4. HUMAN HEALTH

Human health indicators involve toxic chemicals, mutagenic and carcinogenic agents that may harm nervous, immune, cardiovascular and reproductive systems. It is not usual to conduct controlled experiments on humans. Human health assessments need to be obtained by indirect methods such as statistical data on occurrence in the presence or absence of a suspected contaminant (epidemiology). This form of analysis also includes studies of dose-response and often involves non-human subjects from which results are extrapolated to the human population. Indicators include:

- Regional disease distribution (cancer, mutation)
- Dietary analyses
- Acute outbreaks of disease
- Biological deformation in water body

Interpretation is most difficult as the human species is relatively long-lived, thus reproductive dysfunction is not readily measurable, diets are increasingly non-specific and response to contaminants is dependents to some extent on age, ethnicity and gender.

8.5. HUMAN PERCEPTION

Although human perceptions may be highly subjective, they are useful indicators as perceptions are often translated into economic realities such as property values, recreational activities, planning processes and policy considerations.

- Indicators include:
- Current property values
- Resource use
- Dynamics of fishing (commercial and recreational)
- Aesthetics (Algae blooms, odor)

Human perceptions may be obtained by surveys, questionnaires, economic analyses and historical assessments. Interpretations require comparisons of both subjective and objective normative (and geographical and region specific) information.

9. Selecting Indicators

Lopez and Dates (1989) suggest that the selection of indicators needs to be tied directly to the goals and objectives to be achieved and that are scientifically credible. They suggest each indicator should (but not limited to):

- relevant to the stated objectives
- relevant to local people (community)
- measurable
- quantifiable
- sensitive to the goals and objectives
- natural variability known
- response to change over time
- ability to integrate over time and space
- timely
- generally applicable

In addition to be successful, the indicators must consider:

- cost effectiveness
- ease of obtaining information
- have acceptable methods and protocols
- easily understood by audience (community)

10. Other Considerations

In practice ecosystem and human health indicators, in order to have significant meaning, are a combination of parameters, for example, ionic strength, oxygen and turbidity. Too often the measured indicators are not determined over a specified time frame. It is important, for example, when measuring concentrations of chemicals or sediments that the flow rate of a river, or the temperature of a lake, or other environmental parameters be included, as this allows the inference of the significance of the impact of these parameters on both ecosystem and human health.

To be useful and scientifically credible it is necessary that guidelines and criteria for the various indicators be developed and agreed to. It is necessary to know what is the normal range of an indicator without human influence (natural), for example color, turbidity, or peryphyton growth, so that measured values may be compared to the normal variation within the particular system and over a stated temporal scale. Thus, scientifically based criteria (directives) that are credible, must be developed. In addition, threshold values for certain indicators need to be established. These threshold values should be significant to ecosystem structure and function and for societal reasons related to human health.

To obtain a more complete appreciation of future water issues it is necessary to consider interactions of climate change, land use and surface hydrology, groundwater, human systems and adaptation and mitigation measures. Unfortunately there is little data available and considerable debate on future scenarios.

The construction of dams, levees, pipelines and treatment plants, the so-called "hardpath" solutions, which brought about benefits to human society in relation to flooding, irrigated agriculture and hydroelectricity production, also created unexpected social, economic and ecological consequences. People have been displaced, social cultures have been altered, aquatic biota have become threatened, habitats driven to extinction, and some streams no longer flow to the ocean (Nile, Huang He, Anu Darya and the Colorado River).

Gleick (2003) proposed an internationally accepted "soft-path" approach to alleviate this reality. The approach is to improve the productivity of water use rather than seek new "sources". The proposal is to deliver water services and qualities that match users' needs and to apply economic tools such as marketing and pricing and thereby move toward efficient use, equitable distribution of water and develop sustainable systems. He supports the international conferences principles of including local communities in decisions about water management and planning. In order to move in this direction new ways of assessing the effects of management are needed.

11. A Mechanism to Assess Health

As stated earlier, to sustain a healthy aquatic system, it is necessary to understand the processes that occur naturally within the ecosystem, the effects of anthropogenic affects on these processes and the existence of any thresholds, that once exceeded have a negative impact on the environmental goods and services that the ecosystem provides. Thus, in addition for the need for a better understanding of ecosystem processes, we need to add to and integrate the affects of human intervention – management.

A preliminary and simple model is given in Figure 2. This is a simple input-output model where the inputs and outputs may be any one of the indicators, or combination of indicators, that were discussed earlier. The difference in inputs from outputs may be measured in any agreed upon metric and the model allows one to quantify the difference and, in most cases, assign a monetary value to the difference. If the magnitude of the output is significant and is greater than the input, then human remediation, at an external cost, is necessary. On the other hand, if the value for the output is less than the input, ecological processes have mitigated the effects – a free service of the environment. Reed (1990) provides a manual prepared by a task force on natural systems – Natural Systems for Wastewater Treatment. This manual provides examples of input-output models for a number of water resource management systems, including land based and aquatic based systems. The manual also provides economic analyses of various systems that have been constructed in specific regions of the United States of

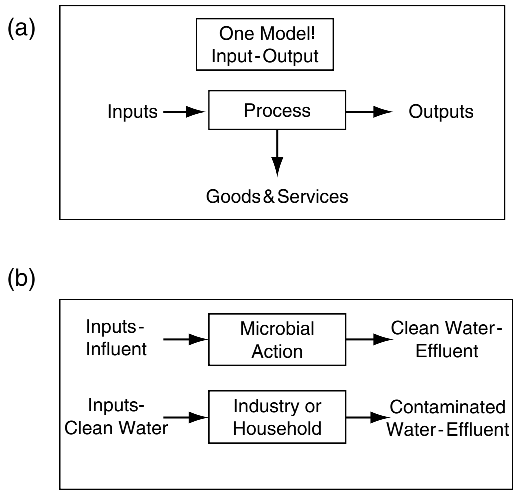

Figure 2. (a) A simplified input-output indicator model using environmental indicators (b) examples of application

America. This provides an example of how natural environmental (ecological) services may be compared to "economic" remedial actions for the maintenance of water quality. It is this type of analysis that allows the preparation of more realistic benefit-cost economic analyses of the value of environmental services. At best, these examples and the ones to follow are conservative "economic" estimates of benefits, as societal values such as biodiversity, recreational potential and bioavailability are not included.

The following examples illustrate the analysis that might be achieved with the input – output model.

Case 1 illustrates the functioning of a constructed wetland as a septic lagoon and its efficiency during two contrasting parts of a year. It is interesting to note that the constructed wetland increases the oxygen content and the concentration of nitrate. Season appears not to be an influence.

Input-Output Modeling

Case 1 – Septic lagoon and constructed wetland

May to October (dry season)

Parameter	Influent lagoon	Influent dam	Effluent dam
Inflow (m^3d^{-1})	41.2		
T (°C)	15.7	16.4	15.3
pH	7.4-8.3	7.5-11.3	7.0-8.9
O_2 (mgL^{-1})	4.7	9.7	1.8
COD (mgL^{-1})	88	80	56
BOD_5 (mgL^{-1})	34	19	13
TN (mgL^{-1})	15.4	8.3	7.0
NH_4-N (mgL^{-1})	7.9	3.22	2.59
NO_3-N (mgL^{-1})	0.64	0.54	0.75
TP (mgL^{-1})	2.17	1.74	1.52
Chlorophyll a(ugL^{-1})		546	336
Phaephytin (ugL^{-1})		122	99

November to April (wet season)

Parameter	Influent lagoon	Influent dam	Effluent dam
Inflow (m^3d^{-1})	60.7		
T (°C)	5.3	5.1	4.8
pH	7.0-8.1	7.2-9.8	6.5-8.4
O_2 (mgL^{-1})	6.3	11.7	3.5
COD (mgL^{-1})	80	75	48
BOD_5 (mgL^{-1})	34	18	11
TN (mgL^{-1})	17.7	12.9	9.6
NH_4-N (mgL^{-1})	6.72	4.38	3.94
NO_3-N (mgL^{-1})	1.2	0.97	1.44
TP (mgL^{-1})	2.05	1.15	0.89
Chlorophyll a(ugL^{-1})		511	328
Phaephytin (ugL^{-1})		122	99

Numbers are all averages over the seasons for 3 years, with the values being stable for all 3 years.

Adapted from: **Steinmann, C.R., Weinhart, S., and Melzer, A.** 2003. A combined system of lagoon and constructed wetland for an effective wastewater treatment lagoon. Water Research 37 (9): 2035-2042.

Figure 3. Input/Output Modelling Case 1

Case 2 illustrates the example of nutrient removal from a salmon hatchery and a comparison to the local "unaffected" stream. In this example, the sitting pond/constructed wetland removed over 99% of the BOD, total phosphorus, total suspended solids (TSS) and almost 100% of settleable solids.

Case 3 is an example of a wetlands efficacy in mediating xenobiotics of various concentrations in mesocosms. There are differences in the rates of "decontamination" between chlorothalonil and chlorpyrifos, but both are effectively removed after 48 hours.

Case 4 is an example of a constructed wetland where the efficacy of nitrogen removal may not be significant in riverine systems. Thus the ecological setting needs to be considered.

Case 2 – Chemical and physical indicators of the settling pond/ wetland system to remove nutrients

Mean Phosphorus concentrations over 15 months upstream from a fish hatchery, at the influent to wetland treatment system (hatchery outfall) and the effluent from the pollution abatement pond that then entered the constructed wetland.

Sample location	Mean (mg/L)	Range (mg/L)
Upstream 1	0.080	0.04-0.2
Upstream 2	0.087	0.04-0.2
Hatchery Outfall (Influent)	0.099	0.04-0.2
Effluent	0.333	0.22-1.3

High end of range was measured during winter, particularly during freshet season.

Schematic:
Hatchery Outfall → pollution abatement pond (settling pond) → 3 consecutive wetland cells → creek

Mean parameters measured over 3 years

Parameter	Influent to PA pond		Effluent from PA pond		Effluent from wetland	
	Mean	Range	Mean	Range	Mean	Range
BOD (mg/L)	38.53	7-97	18.93	4.8-59	3.49	ND-14
TP (mg/L)	1.61	0.24-4.4	0.76	0.04-2	0.13	ND-0.44
NH_4-N (mg/L)	0.67	0.2-1.5	0.43	0.02-1.3	0.11	ND-0.5
TSS (mg/L)	256.6	25.3-806.6	58.01	5.0-261.6	5.02	ND-13.70
Settleable solids (ml/L)	1.39	0-5.1	0.23	0.05	1.1	ND- 0.05

ND- none detected

Percent removal of pollutants in hatchery treatment system

Parameter	PA pond (%)	Wetland only (%)	whole system (%)
BOD	50.9	8.16	90.9
TP	53.0	82.3	91.7
NH_4-N	36.8	75.1	84.3
TSS	77.4	91.3	98.0
Settleable solids	83.5	95.4	99.2

Adapted from: **Michael, J.H.Jr.** 2003. Nutrients in salmon hatchery wastewater and its removal through the use of a wetland constructed to treat off-line settling pond effluent. Aquaculture 226(1-4): 213-225.

Figure 4. Chemical and physical Indicators - Case 2

Case 3 – Role of constructed wetlands on pesticide removal

Concentrations in simulated 'low concentration' runoff applied to constructed wetland mesocosms.

Time (h)	Chlorothalonil		Chlorpyrifos	
	Mean (ug/L)	Range	Mean (ug/L)	Range
0	148	139-156	0.9	0.7-1.1
3	69.4	58.8-79.0	<0.1	<0.1
6	39.9	33.0-46.9	<0.1	<0.1
12	8.8	5.4-14.1	<0.1	<0.1
24	8.7	3.8-17.5	<0.1	<0.1
48	<0.1	<0.1	<0.1	<0.1
72	<0.1	<0.1	<0.1	<0.1

Concentrations in simulated 'medium concentration' runoff applied to constructed wetland mesocosms.

Time (h)	Chlorothalonil		Chlorpyrifos	
	Mean (ug/L)	Range	Mean (ug/L)	Range
0	296	256-329	19.4	13.4-24.7
3	68.4	45.9-92.9	4.7	3.6-6.4
6	18.6	13.8-23.2	2.9	2.4-3.2
12	6.5	1.6-11.6	2.1	1.7-2.9
24	<0.1	<0.1	1.3	1.1-1.5
48	<0.1	<0.1	0.7	0.3-0.9
72	<0.1	<0.1	0.4	0.1-0.8

Concentration in simulated 'high concentration' runoff applied to constructed wetland mesocosms.

Time (h)	Chlorothalonil		Chlorpyrifos	
	Mean (ug/L)	Range	Mean (ug/L)	Range
0	326	256-358	19.9	18.5-21.5
3	157	150-164	4.9	4.4-6.0
6	92.7	53.4-118	1.5	0.8-2.0
12	33.7	19.4-45.4	0.8	0.6-1.2
24	1.3	<0.1-2.7	0.3	0.2-0.5
48	<0.1	<0.1	0.2	0.1-0.3
72	<0.1	<0.1	0.1	<0.1-0.1

Adapted from: **Sherrard, B.M, Bearr, J.S., Murray-Gulde, C.S, Rodgers, J.H, Jr., and Y.T. Shah.** 2004. Feasibility of constructed wetlands for removing chlorothalonil and chlorpyrifos from aqueous mixtures. Environmental Pollution 127(3): 385-394.

Figure 5. Role of constructed wetland on pesticide removal - Case 3

The four Cases provide examples of the utility of the input-output model as the initial phase of estimating both the costs of water quality remediation and the benefits of utilizing "environmental services" in constructing the remediation. These examples are illustrative of effective remediation in the contaminated water systems and how the system is cleansed by biological/ecological processes and there is no residuals of concern, such as filters, or absorbents that must be dealt with by some subsequent action. It is relatively straight- forward to apply economic analyses to these systems. Of course, one needs to incorporate both capital and operating costs.

Case 4 – Effect of season on nitrogen dynamics in constructed wetlands

Parameters	Low N Loading	
	Inflow	Outflow
inflow (m^3/d)	1053 ± 75	955 ± 122
$NO_3 + NO_2$ (mg/L)	4.6 ± 0.5	3.4 ± 0.43

Parameters	High N Loading	
	Inflow	Outflow
inflow (m^3/d)	2853 ± 127	2569 ± 147
$NO_3 + NO_2$ (mg/L)	12.3 ± 0.93	7.7 ± 0.66

Adapted from: **Spieles, D.J., and W.J. Mitsch.** 1999. The effects of season and hydrologic and chemical loading on nitrate retention in constructed wetlands: a comparison of low- and high-nutrient riverine systems. Ecological Engineering 14(1-2): 77-91.

Figure 6. Effect of season on nitrogen dynamics in constructed wetlands - Case 4

Chichilnisky and Heal (1998) calculated that to replace the natural water purification services of the Catskill Watershed for the city of New York would require a filtration plant with a capital cost of about $8 billion (US) To restore the watershed's efficiency (ecosystem services) would lead to a "net-present cost" to society of $17 billion (US). The example illustrates the connection between human systems and ecological systems.

12. The Coupling of the Human and Natural System

Humans depend on ecosystem structure and function not only for biological survival but also for social (economic) needs and desires. The inter-connections are many, complex and need for further scientific study. Water, an essential component of both ecosystems and human systems, provides a link between these two human perceived systems. Thus water may be used as an indicator of ecosystem and human function and, therefore the metaphor of health. To use water as an indicator of "health", it in turn, requires indicators that are meaningful and useful; so that we humans can make more sustainable decisions and not exceed the ecological carrying capacity of those systems we "manage".

The reactions/processes among ecosystem components and human derived actions are innumerable. Thus, to provide an estimate of anthropogenic effects on this essential substance, water, environmental indicators aid in this evaluation. These indicators must be recognizable, understandable, credible acceptable by the community and decision makers, be useful for evaluation of human objectives, and reflect conditions that are far from the normal conditions of the aquatic system. These indicators must incorporate the realities of ecological carrying capacity, resilience of systems and the realities of thresholds and irreversible change.

Incorporation of indicators into input-output models allows the conceptualization of the costs of remediation of anthropogenically affected water and provides a framework for assessing benefit/cost analyses of both human endeavors and ecosystem services. thus environmental indicators are the communication agents of human impact on water, the social and economic costs and ultimately a metric of both ecosystem and human health.

13. Conclusions

Water is the environmental integrator and a vital component of nature, thus both ecosytems and the embedded and dependent human system. Each defined water entity has an inherent capacity to function and maintain finite levels of function, called environmental services. If the limits of the finite system are exceeded the system ceases to provide the same services. To assess the ability of a water sustem to maintain a level of desired function indicators that are charactristic of the system may be used to ascertain the the effects of management or the potential impacts on the carrying capacity of the system. These environmental indicators are mesures that are significant or at best correlated with water inherent character to provide environmental services. These indicators may be used also to provide quantitative assessments of management effects through the employ of "input-output" models. Measure of an indicator prior to a management activity, for example organic level and following sewerage disposal, provides an index of impact that may be used for economic and mitigation protocols. Environmental indicators are necessary as human knowledge is incomplete and most ecological processes that affect the environmental carrying capacity of are non-linear, complex and often unknown.

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DEVELOPMENTS IN PARTICIPATION WITHIN INTEGRATED WATER MANAGEMENT

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Abstract. In this paper we discuss new practices in water management regarding the involvement of people and stakeholders in the policy-making process. We intend to identify criteria that help in selecting a suitable type of participation for a specific case. After a broad exploration of some basics in literature about decision-making and public participation, we concentrate on adaptive management resulting from the ecosystem approach. Based on the level of interaction, we indicate six levels of participation between water managers and actors in society. Keeping in mind a distinction between a pluralist and a corporatist approach, we proceed with major criteria that play a role in the selection of a suitable design for a participatory decision-making. We conclude with some important questions that should be addressed in order to find a model that enables water managers to decide about their optimal styles of public and stakeholder participation in practical cases of decision-making.

Keywords: stakeholder participation, interactive policy-making, integrated water management

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1. Introduction

The word ‘participation’ comes from the Latin noun ‘pars’, which means ‘a part’, and the verb ‘capere’, which means ‘to take’. So, in general participation can be described as ‘to take part or be involved in something’. The adjective ‘public’ in the broadest sense refers to ‘all the people of a country or community, including governmental and non governmental organisations.’ Accordingly, public participation in integrated water management can be defined as ‘the involvement or taking part of all the people of a community in an equitable, efficient and sustainable use and management of available water systems’.

Participation of the public in water management in itself is not new. For example, the water management boards in the Netherlands emerged from a self-organising process of individuals starting to co-operate to defence themselves against the highly dynamic tidal waters and to ‘make land out of water’ (for housing and food production). During the centuries, with increasing human population and development levels, economic growth and (technological) interventions, the complexity of social-ecological ecosystems increased.

On a global scale, a diversity of decision-making and management systems emerged, based on different cultural backgrounds, values and paradigms. The concepts and strategies of public participation differ with various decision-making and management styles, going from totalitarian to democratic. In general, a dominant trend towards more interaction between water managers and the different actors in society can be observed.

We can state that, in sustainable water management, there is even an urgent need for interaction with societal actors in decision-making processes. It requires a new trans-disciplinary culture: ‘Sustainability requires (…) a new production of knowledge, the consideration of cultural issues, the recognition of the territorial system as a linked social-ecological ecosystem and the understanding of self-organisational processes’ (Pires Rosa, 2003). With their knowledge of the ecosystem and their direct stakes in its health, communities are often the most prudent ecosystem managers. The citizens (including minorities and vulnerable people) have to be considered as key factors for decision-making’.

The Ărhus Convention (UN-ECE, 1998) recognises the citizen’s right of access to environmental information, to public participation in decision-making and to justice in environmental matters. The guidance on public participation in relation to the Water Framework Directive of the EU (2002) states that the main purpose of public participation is to improve decision-making by ensuring that decisions are soundly based on shared knowledge, experiences and scientific evidence, that decisions are influenced by the views and experience of those affected by them, that innovative and creative options are considered and that new arrangements are workable, and acceptable to the public (WATECO, 2002)

'Through participation, long term, widely acceptable solutions for river basin planning can be arrived at. This can avoid potential conflicts, problems of management and costs in the long term'.

2. Participation and Uncertainty

Some decades ago, Thompson and Tuden (1995) considered means, ends and uncertainty as key variables of public decision making. From these three, the 'means' refers to the knowledge of how to do something, in other words the instrumental knowledge. The 'ends' refer to the goal: the purpose and desired outcome. The third, 'uncertainty', refers to the fact that each practice of public participation is subject to a certain level of uncertainty. Dependent on this level, a set of problems or issue must be discussed to clarify the conditions and to identify appropriate expectations and responses (Lee, 1993; Christensen, 1999). Inspired by Thompson and Tuden (1995), Lee (1993) considers that such situation will depend on whether there is agreement or disagreement in beliefs about the causation (related to the means) and either there is or there is no agreement on the outcomes (related to the ends). The distinction drawn in the matrix of Fig. 1 is between outcomes and causality.

So, the situation D may converge to the situations B or C in function of the comprehension, clarification, identification and articulation of the problem: when the reformulation of the problem is successful and the uncertainty in relation to the ends have been reduced, then attention can be focused on the means of the solution of the problem, then it is converged to a situation B. When the discovery of the problem requires clarification and the debate of alternative possible solutions, trying to reduce the uncertainty referring to the means, then attention

		beliefs about outcome	
		agree	disagree
beliefs about cause	agree	A. Computation in *bureaucratic* structure	C. Bargaining in *representative* structure
	disagree	B. Judgement in *collegial* structure	D. *settling* CONFLICT *planning*

Figure 1. Deciding and intervening: some organisational alternatives. Based on Lee (1993), modifying Thompson and Tuden (1959)

can be focused on the adaptation of the distinct preferences (multiple ends), converging to situation C. These different processes of planning require a distinct type of participation of the citizens (Christensen, 1999).

- *Situation A* – it is the realm of bureaucracy; known rules or solutions are being applied; it is an expert-driven process based on rational activity where the public is informed;
- *Situation B* – it is the realm of science where scientists and professionals are asked to find solutions for problems and to find ways to get consensus; it takes into account some public participation;
- *Situation C* – it needs to harmonise divergent ends by bargaining and negotiation among parties; there must occur an active public participation which needs a collaborative and pluralist structure; this is the adaptive model;
- *Situation D* – there is no structural solution, so it must find strategies designed to move conflicts from the irresolvable to one of the cases which experts know how to handle structurally, by planning (B) or settling (C).

The approach of involving citizens in participation, generally used within traditional planning, has been essentially of an informative type, not providing an interactive planning. As a general rule, this participation is only required in late phases of the process of decision-making, being many times considered unsatisfactory because they don't manage to influence the decision. This way of participation doesn't represent a problem when the consensus is generalised, however in situations of great complexity and uncertainty, it may generate conflicts and distance from the citizen towards the definition of alternative solutions. Christensen (1985) considers that in the so-called standardised programmed interventions (situation A, Fig. 1), the need of participation is not so relevant; in situations where the targets are agreed upon but where the means are unknown (situation B, Fig. 1) or in situations where there is disagreement about the targets, notwithstanding the fact of the solutions being known (situation C, Fig. 2), the need of participation is relevant, however, the way in which participation should be processed must be analysed case by case; in situations where there is no agreement in what concerns targets and where the solutions are unknown (situation D, Fig. 1), the participation (in itself) does not lead to a solution. Than the problem must be redefined as we have already seen. The negotiation process is all the more pressing when the object of study is more complex and problematic, such is the case in areas with a high rate of environmental decay, where it is in quantitative terms insufficient that the planning process involves a high level of participation. Above all one needs an efficient negotiation and so an active participation is necessary where the public shares decision-making with government and where the public performs public tasks independently.

Examples can be found in various types of ‘adaptive management’. For support tools, see for example Welp (2001).

3. The Adaptive Approach in Social Natural Ecosystem Management

Adaptive models demand choices and trade-offs. The selection of these is driven by values through an active public participation which contributes by the information gathering, analysis, decision-making, implementation and capacity-building, and monitoring and evaluation of projects. It is assumed that there are no isolated natural systems and no isolated social systems (Vitousek et al., 1997). The human beings are an integrated part in every natural ecosystem and there is a recursive and interconnecting influence among them with their interactions, interdependence and dynamics; one speaks of social-natural ecosystems and of integrated human ecosystems, where the human being is the main agent. The integrity of these ecosystems depends on the adaptive capacity of overcoming a crisis or shock; this depends on one’s resilience and endurance capacities.

All this complexity within social-natural ecosystems needs an organisational and leading culture which is completely different from the traditional ones, demanding empowerment, to achieve a structure which takes horizontal and inverted decisions, aiming at an adaptive organisation based upon learning processes. An open, fluid and integrated management is needed from where information circulates to promote the self-organisation capacity of the social-natural ecosystems.

The adaptive approach strengthens the ecosystems management strategies (Lee, 1999). Before the social and environmental problems, the citizen and the collectivities should break out for a pro-active function through adaptive answers to the changes. Facing all the complexity and uncertainty inherent to ecosystems, Lee (1999) advocates the need of ‘adaptive management’. The concept of ‘adaptive management’ was developed by ecologists to shelter the uncertainty, the complexity and the coming of unexpected happenings in the natural ecosystems, having appeared in the literature of natural resources and environmental management, mainly from Holling (1984), from Walters (1986) and later from (Lee 1993) It appeared as a type of application which enables learning through experience at the time of the implementation of management of natural resources. It was considered that in the most complex situations, where a high rate of uncertainty exists, a more effective use of the resources occurred, if adapting and learning were emphasised. Lee (1993) advocates integrating experimentally focused policy design and negotiative political interaction. This combination of adaptive management and the bounded conflict of pluralist democracy is what he understands by ‘social learning’. He considers that adaptive management ‘is a synthesis of science and policy that treats policies as large-scale experiments. Bounded conflict (...) is a combination of politics, negotiation, and other means of promoting uncomfortable change, which provides tools for establishing shared goals and probing the bounds of co-operative effort. Like compass and gyroscope, the two parts of social learning are 'complementary' (Lee, 1993). However, recently, the concept of adaptive management is applied to a wider scope of scales, which vary from landscapes (big ecosystems at a regional scale), to river basins (Cortner and Moote, 1994; Coape Arnold et al., 2003), amongst others being defended by land use planners (Briassoulis, 1989; Lajeunesse et al. 1995). In these contexts, the ecological introspections of 'traditional' adaptive management are combined with social learning (Lee, 1993) and with the perspectives of the social institutions (Gunderson et al., 1995; Dovers and Mobs, 1997) so as to include important stakeholders, to balance the distribution of power among the stakeholders and endeavour towards processes of solving conflicts and find agreements. According with Pahl-Wostl (2003), the concept of 'social learning could be described as learning by groups – authorities, stakeholders and experts – to handle issues in which all group members have a stake – such as the management of a river basin'. This long-term process requires a continuous participation and 'capacity building' which converge to a 'collaborative and adaptive capacity' that possibly builds up to awareness, knowledge, skills and operational capabilities. The application of the ecosystem approach in the natural resource and environmental management will help to achieve a balance between conservation, sustainable use and equitable distribution of benefits. This emphasis is based on the application of appropriate scientific methodologies focused on the different levels of organisation which include the essential structures, processes, functions and interactions between organisms and their environment. The organisation recognises that the human being with his/her cultural diversity builds up an integral component of many ecosystems. There is no single way of implementing the ecosystem approach, as this depends on local, provincial, national, regional and global conditions. One of the most important elements here is the level in interaction that water managing governments allow. In the following paragraph we elaborate on this.

4. The Participation Ladder

Governmental agencies can adopt several roles in the participation process, each with its own degree of interaction with different societal actors. These roles can be understood as hierarchical steps on a 'ladder of participation'. With every step up on the ladder, interaction between government and participants becomes more intense. In Fig. 2, the second column defines the style of

Step	Style of Governance	Role of Participant	
6	**Facilitative**	Initiator	*Active participation*
5	**Co-operative**	Co-operating partner	
4	**Delegating**	Co-decision maker	
3	**Advising**	Advisor	
2	**Consultative**	Consultant	*Passive participation*
1	Open authoritative	'Target group' of information	
0	Closed authoritative	Obedient citizen	

increasing interaction

Figure 2. Ladder of participation, modifying Van Ast & Boot (2003); the higher on the ladder, the stronger the interaction

governance and the third column the role of participating actors in the policy-making process.

The 'ladder of participation' is an indicator of the government's attitude towards participation. At the bottom of the ladder there is no real participation at all. In this *closed authoritative style,* societal actors do not interact with water managers in the decision-making process, the first one just do what they are told by the last ones. The smallest degree of participation can be found at the first level on the ladder, in which the position of the government can be characterised as *open authoritative*. The actor is just a target group of research or information. At the second level the government is *consultative*, and society is principally asked about possible actions to be taken by the government. From the second step down, one cannot really speak of interactive policy-making. The third step of the ladder can be called *advice governance.* Here, society takes a role as advisor. At the fourth level, the government *delegates* tasks, and actors become co-decision makers. At the fifth level from the ladder, with a *co-operative* government, societal actors are partners in policy making. At the highest, sixth degree of interaction, the government plays a *facilitative* role. In this situation, societal actors take the initiative.

Generally speaking, two main types of interactive policy-making can be distinguished. The first involves the broad public in the decision making process. This *pluralist type* can be considered as the ideal type of interactive policy making in a democratic society, since every citizen has the possibility to exert direct influence on decision making processes. Referenda are an example of this type. The second type of interactive policy-making involves (organisations of) stakeholders, related to a specific policy-issue in the decision making process. In this way, representatives of specific interests operate more or less in an equal position to governmental authority and to other stakeholders. An example of this *corporatist type* of policy-making are the negotiations among government, labour unions and employer organisations about collective labour conditions for an overview of different types of state-society-market interactions, see Ham and Hill (1993).

In the idealised state of a participative democracy, the aim would be to generate the highest degree of interaction possible. This means that the possibility should be created for societal actors to decide together in the policy-making process either directly or indirectly. At least for efficiency reason, this does not necessarily mean that in all cases, actors should be involved at every stage of the policy process.

Theoretically, there are two main advantages to (both types of) participation. Firstly, the quality of a decision is potentially higher because the different views and specific knowledge of people involved, can be taken into consideration. Secondly the interaction enables exchange of information, which can lead to a better understanding of the ins and outs of the specific situation and can contribute to public acceptance and support. This situation is the opposite of the practice of negotiations that presently go on behind closed doors, involving selected groups only. Involving too few stakeholders is a threat to democracy, which is especially relevant for the corporatist type of policy making. With regard to this type of interaction, it is therefore crucial to be very careful in keeping negotiation processes transparent.

From a governmental point of view, a disadvantage of these types of open communication is the possibility that actors striving for other goals than the government, undesirably get more influence. In this way, a high degree of openness could decrease the extent to which government agencies can attain their public goals and can inhibit rapid policy implementation. The first problem calls for an adequate institutional framework for interactive policy making, securing the position of governmental agencies in the negotiations. The second problem calls for careful preparation of the participation process, with at least agreement with the stakeholders about aspects like policy goals and policy means. This can substantially speed up the decision making process and its implementation.

With regard to the *corporatist* type of interactive policy-making, it is important to make an exhaustive inventory of possible parties to be included in the policy-making process. Therefore, prior to the choice of a 'style of governing', an actor-analysis needs to be made. This relates both to the choice of internal actors within the government structure itself and to the choice of external partners. For the realisation of policy goals, the behaviour of stakeholders can be a crucial factor for success. Most of the actors all have their own view on solutions for the problems they perceive. For example, farmer organisations, environmental groups, associations of house-owners and individual citizens may all have different ideas about measures that change the physical, chemical or biological characteristics of a river basin. By giving these stakeholders a full position in the decision making process, objections that might arise in the policy implementation phase may be prevented.

5. Important Criteria for the Style of Participation

In order to choose a step on the participation ladder, water managing authorities have to take into account different criteria. Important for example is the scale of the water system: ocean, coastal zone, river (basin), tributary, stream, pond. Not every decision is about the whole water system; some only consider a small stream, others are of importance for the whole river basin. We can also easily make a distinction between territorial levels, like global, international, national, regional, local and personal. And not at least we need to discriminate between the hierarchical levels of governance, like international body (river basin committee or economic union), country, state, province, region or municipality.

With acknowledgement of the subsidiarity principle, which takes the decision to the lowest level possible, the scale is of large influence on the style of participation. Other important factors are amongst others 'gender', 'social-cultural and religious aspects' and 'information and trust'

Apart from governmental hierarchy, we can find different levels of hierarchy in stakeholders. Every type of stakeholder participation requires a certain level of stakeholders involved and makes a explorative 'stakeholder analysis (interest and influence)' necessary.

6. Towards Interactive Water Management

Both the pluralist and corporatist type of participation can improve governmental policy and hence the management of water systems. The development towards more participation fits in a global evolution in the water management paradigm, where step by step a development towards 'interactive management' of international river basins can be identified (Van Ast, 2003).

Interaction refers here to the society on the one hand, and the water system on the other (Fig. 3).

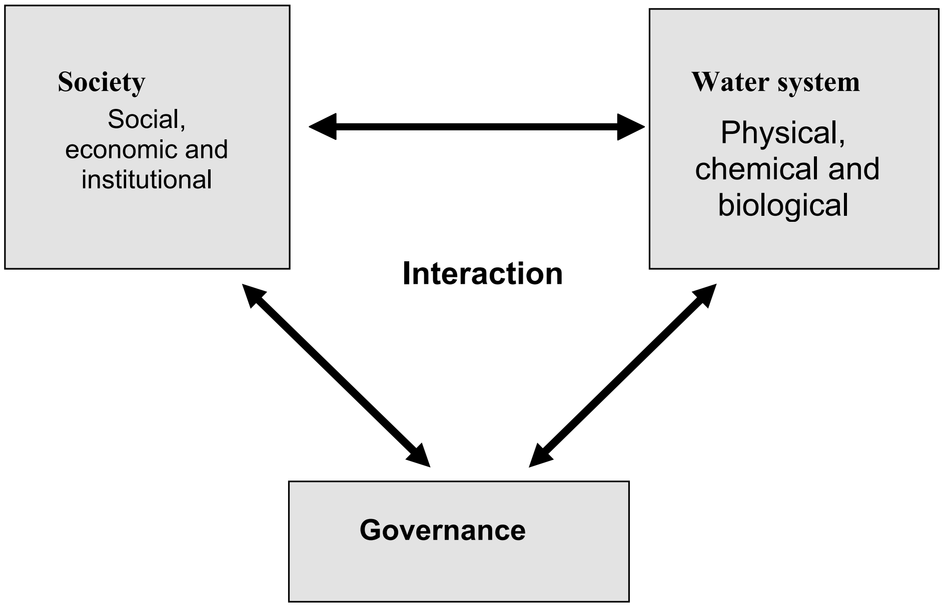

Figure 3. Interactive Water Management; water managers govern in an interactive way both the society and the water system

The time that water authorities, just as other governmental institutions could decide about plans, projects and policy aims independently (without involving 'society'), has been left behind. Water managers should monitor relevant processes in society (Ham and Hill, 1993) at all times. This makes it possible to adequately react to changes in human behaviour which have impacts on water systems. In addition, monitoring societal processes makes it possible to react to opportunities for the development of new policy approaches. Besides interacting with the society, water managers' relationship with water systems should also be based on interaction. This is why the 'water system' has been included in Fig. 3. Interaction with the water systems means that interactive water managers are in a continuous dialogue with the water systems (i.e. the different ecological parameters). At every moment they have an overview at their disposal of the state of the river system they manage. This requires intensive monitoring of chemical, physical and biological parameters.

The third arrow of interaction in the Fig. 2 refers to the relation between society and the water system. It appears that by the time less and less people are interacting with their natural surroundings. Can we expect from inhabitants of urban areas that they understand the value of a healthy water system if they do not even have the chance to come into contact with nature? Nowadays, children are educated in many profession-related disciplines. However, the time spent on teaching interdependencies with the natural environment, is only diminishing. At the same time, our cities leave only small opportunities for children feel for example elements of water systems. This basic type of interaction between people and planet, makes participatory decision-making even more difficult.

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CONCLUSION

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Water is essential for a wide range of human activities and it exists in relatively finite amounts. At the most fundamental level, water is absolutely essential to human health and survival for drinking, for bathing and sanitation, and for food production and irrigation.

As population grows, societies need more water for both daily human use and for food production (usually through increased irrigation). Rapid urbanization and the expanding use of water in industrial processes are also contributing to an increase in demand.

Water quality, prevention of pollution, and ecosystems preservation are also crucial points when dealing with water management and water use.

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Then, global climatic change might further complicate the water supply. As greenhouse gases accumulate in the atmosphere, the world's average temperature might rise and precipitation patterns altered in many parts of the world. This could lead to higher levels of rainfall in some areas and lower levels in others.

Water management represents a crucial issue for the society overall in areas where water is shared by two or more countries, and where, of course, disputes may occur. This danger is particularly acute in areas where rainfall is scarce and several countries depend on a single major source of water for their basic needs (like in the Nile River, the Jordan, the Euphrates).

When dealing with water management, different issues should be combined: water demand, water quality, irrigation and food production, ecosystem preservation, cost minimization, technological options, legislative frameworks, social impact. The identification of sustainable pathways for proper land use development is a typical example. In this case, the main trade-off that takes the most problematic decisional aspects is between the anthropogenic actions and the conservation of natural resources. In this respect, the water system and its quality is taken into account as one of the most important indicators, which affects the sustainability of the agricultural activities on a rural territory.

The general note that comes out from this book is the necessity to find instruments and methods for planning and management strategies, as well as instruments, methods and appropriate indicators for evaluating the environmental impacts of the possible intervention and of the no-action strategy. To this end, it is necessary to consider different classes of problems that require separate modelling techniques (concerning both the physics of the system and the ecosystem): groundwater (aquifer pollution, seawater intrusion), surface water (rivers, lakes, reservoirs, estuaries).

In both cases, a main difficulty is the integration of the different issues concerning environmental modeling and the various points of view coming from the different disciplines involved.

For example, from an engineering point of view, three approaches can be seen: the infrastructural, the technological, and the computer and system sciences points of view. Infrastructures are built to give efficient services to population and water use, technologies can be useful for example in finding new water treatments useful for water quality respect, computer and system sciences may provide efficient data assimilation and models that can help in finding planning and management strategies, in predicting the effects of the different intervention on the environment and vice-versa, in finding efficient control, monitoring, communication and image processing technologies. On the other end, economists aim at studying the market and suitable pricing strategies, and quantifying in economic terms the environmental impacts. Then, the biology viewpoint aims at studying the biological system, in order to protect it and to analyze possible solutions for water quality, finding and quantifying the carrying capacity of an ecosystem, and clearly stating conditions of "good status" for water bodies and associated ecosystems.

Although the complexity and uncertainties of social and natural systems, associated with unpredictable events urge for holistic planning and management to integrate natural sciences, social sciences and traditional values, in research rarely emphasis is posed on the interactions with the biological and agricultural systems as well as with the land use and the ecosystem in general. Since no social or no natural system is isolated, and uncertainties occur in knowledge and in values, only an approach integrating natural sciences and social sciences and considering traditional values is efficient and sustainable.

The differences in characteristics related to climate, geography, society, economics, politics and culture, make a blueprint for a planning methodology not possible. Specific situations need an adapted approach, not only regarding the knowledge, but also considering communication differences according culture and political systems

This is mainly due to the fact that the vision of sustainability is demanding ecosystem approaches (that take into consideration ecological and cultural integrity) and adaptive approaches (which depend of community management, social flexibility and learning), integrating the values and the perceptions of communities.

Considering the complexity and the uncertainties of social and natural systems and the associated unpredictable events, it seems that the contemporary planning systems are no longer pertinent.

In this book, a methodological framework for IWM has been given, together with the experiences and the problems related to specific case studies all over the world.

The different methodological approaches reported in Part I show the importance of ICT tools, participation approaches, Environmental Decision Support Systems (EDSSs), Civil protection actions.

Of course, a crucial point is the suitable interpretation and use of huge amounts of data by systematic measurements. Semi-automatic knowledge extraction from data has gained great importance within the economic and scientific community, and in particular Knowledge Discovery from Databases (KDD) has emerged as a framework where a plethora of techniques for identifying useful and understandable patterns in data have flourished. However, the future is seen in using hybrid approaches combining models of different types and following different modelling paradigms, including the combination with physically-based models. Moreover, it can be foreseen that the computational intelligence (machine learning) will be used not only for building data-driven models, but also for building optimal adaptive model structures of such hybrid models.

Generally speaking, ICT technologies are a challenging issue for helping water managers, in particular for data assimilation, knowledge acquisition and for the models useful for the planning and management of water resources. Together with the growing complexity of information to be gathered and to be handled, the importance of support by Environmental Decision Support Systems (EDSSs), Geographical Information Systems and simulation and optimization models is increasing. The appropriateness of the approach in water management is widely demonstrated in literature (Matthies et al., 2007; Soncini-Sessa et al., 2003; Denzer, 2005; Wierzbicki et al., 2000; Sepaskhah et al., 2006).

Different layers should be taken into account within an EDSS, in order to efficiently support decisions: monitoring, database, GIS and models (integrating the different physical/chemical/biological sub-systems), decision support system layers (mainly based on optimization techniques). Each layer, which may be more or less distributed in a territorial context, can offer a reliable service to the higher layers. Moreover, the link between adjacent layers should be guaranteed by adequate telematics communications.

As regards the application of optimization techniques for the management of groundwater quantity and quality, Das and Datta (2001) present a state of the art of the different optimization approaches that have been applied to groundwater management. Specifically, the combined use of simulation and optimization techniques has been demonstrated to be a powerful and useful approach to determine planning and control strategies for groundwater systems (Katsifarakis et al., 1999; Psilovikos, 1999; Naji et al., 1999; Shamir and Bear, 1984; Willis and Finney, 1984). In these works, the simulation model component of the management models is generally based upon the partial differential equations (PDEs) of groundwater flow and solute transport or upon multicell models able to consider water and water quality balances. Depending upon the physical processes considered in the management model, either the flow equation, or the solute transport equation, or both, are used in the simulation. With specific reference to saltwater intrusion management problems, Shamir and Bear (1984) have determined optimal annual operation of a coastal aquifer by using a multiple objective linear programming approach based on a multicell model of the aquifer and a network representation of the hydraulic distribution system. Instead, Willis and Finney (1988) defined a planning model for the control of seawater intrusion in regional groundwater systems, structuring the management problem as a control problem (i.e., making use of real-time information in taking operational decisions).

On the whole, the definition of EDSSs must not be restricted to a piece of software but should include a set of supporting methodologies/techniques, not coded in form of computational algorithms, which facilitate software development, implementation in a given institutional context and application to a specific management problem. In this sense, creative system modeling and participatory approaches seem to be adequate approaches to be adopted. This is of course of vital importance in countries where water management may create conflicts and transboundary water management is a crucial point.

Finally, it is worth mentioning the role covered by civil protection in IWM and in particular in disaster management (i.e., floods). It seems clear that models are helpful (or necessary) tools for social awareness, and, in particular, multi-sensor systems are important tools which need further development and research. The main problems can be found, from a technical point of view, in the different resolutions of monitoring and in the different interpretation techniques of the operational procedures. Then, another problem to be carefully considered is the translation of the increasing complexity of a what is produced on technical level to stakeholders and decision makers into a language of damage and loss.

As regards specific aspect of IWM and case studies, the applications described in this book address important conclusions and suggestions for the future for each of the very different environments that have been taken into account. In the following, some important guidelines are summarized in connection to the reported case studies. In particular, different classes of problems can be highlighted: discussion and examples of general strategies drawn from regulation and participatory approaches, decision tools based on optimization and systems analysis, industrial pressures and risks, eco-hydrology modelling, water quality modeling and pollution preservation. In all these classes of problems, the transboundary aspect is generally seen as an issue that complicates the decision problem. In particular, in this case, the need of finding strategies, based on efficient modeling instruments (that can be accepted by different countries without creating conflicts) is strongly felt.

As regards water management strategies applied in specific case studies, what emerges from different case studies, like in the Scheldt basin, is that participation is a valuable tool for River Basin Management Plans, in order to explore different opinions and viewpoints trough discussion. In particular, reliability, stakeholder representatives involvement, procedural aspects, psychology of changing opinions, negotiation and communication, and decision support can be well embedded in the methodology, in order to find the overall policy question 'how to reach sustainability and good ecological status with the lowest cost and maximal social acceptance'.

The paper "the role of the HELP program" shows that the main aim should be to facilitate the dialogue between hydrologists, social and economic scientists, water resources managers, water lawyers, policy experts, river basin stakeholder communities in order to set a research agenda driven by local policy issues and with the objective that society benefits. In particular, specific activities should be: promoting stakeholder dialogues, defining interface between water policy and law with science, identify basins vulnerable to global change, integrating forest and water issues, determining how food and water policy issues can be addressed, achieving a more integrated, scientific approach, addressing scientific questions where scientific infrastructure is lacking.

Instead, as regards decision instruments for IWM, quantitative decision tools to be integrated with participatory analysis include optimization, simulation tools, monitoring systems. When optimization is included, the first phase is to identify the decision variables, the objectives and the constraints. Then, simulation models should be adapted to the specific case study and decision problem.

The Integrated Water Management in the Seven Cities basin (and in the Azores Islands in general) deals with the interaction among the use of fertilizers, timber, milk production, land use, and water quality preservation. The approach is to integrate agro-environmental models and an economic model, in order to manage water demands and define efficient land use. Different scenarios and indicators should be defined and multiobjective techniques are approaches that can be used for efficiently satisfying the different objectives, taking into account of the various indicators.

Within this framework, an important issue for research activity and water management efforts is the development and test of modeling tools, monitoring campaigns, and approaches in order to assess and analyze the different pressures at which water is exposed (i.e., saltwater intrusion, agriculture, etc.).

A pressure on water quality depletion, water use, and ecosystems is surely saltwater intrusion. In this book, a complete and good example is the coastal freatic aquifer of Cervia (Ravenna, Italy). In this case study, the situation created by saltwater intrusion is heavy and dangerous for vegetation and water quality depletion. In fact, the most of the topography is under sea level and this implies a very critic position for water managers. The causes of intrusion in this case are mainly due to contamination from canals open to the sea, drainage of farmland, groundwater extraction from wells along the shoreline and from private wells. The situation in then made more critical by the fragmentation of authorities responsible for planning.

The International Commission for the Protection of Lake Constance (IGKB) has worked with success on water management and its acts obtained broad consensus. The focus is on eutrophication issues and, since this is the case of a lake characterized by transboundary issues, the problem is that the implementation of measures leads to conflicts between users. Thus, an intensive exchange between scientists, experts, managers is needed. The most important measure is the establishment of a waste water treatment plant, in connection with the development of a philosophy for lake management based on ecological aspects. Despite of the successful tackling of eutrophication, water protection and management are not finished by having established waste water treatment plants. These need a continuous technical maintenance and adjustment in order to keep them functional. Only with these efforts it is possible to keep phosphorus concentrations at the present low level. Problems into the future are mitigating the diffuse sources (mainly from agriculture) and the “chemical cocktails” still released by human activity that pass waste water treatment plants and threaten biota.

Managing water use means also to deal with reservoirs planning and management, according also to the economic changes due to droughts and floods. This is well described and faced in the Iskar reservoir case study (Bulgary). The main problems depend on the decline of water levels in reservoirs, that is dangerous in terms of water quality and of the different water demands satisfaction. The environmental problems to deal with are eutrophication from agriculture, salmon fishery impacted by canalization, soil pollution from agriculture, water demands satisfaction.

As mentioned before, another aspect to be taken into account in IWM is the interactions between hydrology and the ecosystem.

The wetland habitat protection of Narew basin (upper system) highlights the growing pressure on the use of water resources and also growing concerns on the ecological status of surface and ground water dependent ecosystems. The dynamics of these wetlands are characterized by flooding and hydrodynamic models are used to evaluate the best release policy of an upstream water reservoir. Ecological values protection is addressed by purchasing the land from the farmers or subsidies in the frame of agro-environmental schemes of EU. The proposed approach is based on numerical models combined with ecological expertise, and it is assessed that the main problems regard the lack of data and the high cost for calibration.

Another important ecological system in which eco-hydrology aspects necessitate to be investigated is related to the US (south east) South Carolina Coastal Plain. First of all, the need of information and the long term monitoring are essential pre-requisites in order to build efficient models, testing and evaluations. In particular, it seems important a combination of field studies and modeling applications. This should also take to an increased level of collaboration and thus to abilities in addressing water resources issues.

Another issue that is considered in this book is the pollution (or the risk of pollution) associated with industrial settlements. For this kind of issues the impact of a nuclear power plant is evaluated. As a matter of fact, the natural lake serves as a cooler. First of all, it is necessary to define ecological and human carrying capacity of water ecosystems, through suitable indicators such as temperature. The main approaches regard participative management tools, clear action programs, restoration of water courses and water resources.

The book ends with a description related to the discussions that emerged from the working groups about the themes: environmental indicators and participation aspects.

In particular, it is stressed the concept that suitable indicators should be identified and that the conceptualization of ecological carrying capacity is needed. Healthy ecosystem is necessary for a healthy community. Water scarcity by many authors is now defined not by volume available per capita, but by amount of safe water per capita.

As regards, participation, new practices in involvement of people and stakeholders are needed. Participatory decision making starts with two major criteria: Model that enable water managers to decide about optimal styles of participation; Public-decisions soundly based on shared knowledge.

In addition, a special attention should be addressed to the water management in the case of transboundary and shared water resources. Of course, the management is more complex than in one nation because of different political systems, different cultures, different languages, different economical situations.

In conclusion, there is still a lot of work to satisfy the need for additional instruments that favor successful processes of cooperative management and the creation of 'formal' procedures in Integrated Water Management. This book wished to be a first step in this direction.

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