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Conflict Resolution in Water Resources and Environmental Management

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ISBN 978-3-319-14214-2 ISBN 978-3-319-14215-9 (eBook)
DOI 10.1007/978-3-319-14215-9

Library of Congress Control Number: 2014958572

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

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Chapter 1
A Systems Perspective of Conflict Resolution in Water Resources and Environmental Management

Keith W. Hipel, Liping Fang, Johannes Cullmann and Michele Bristow

Abstract The many contributions contained in this book regarding the theory and practice of effectively addressing conflict in water resources and environmental management are put into perspective in this chapter. More specifically, the contents of each of the subsequent fifteen chapters are categorized within four main parts according to the systems methodology that is employed and the type of case study to which it is applied. A metaphor called the "knowledge ladder" is utilized to explain how one can ascend a ladder from data for evaluation at the first rung, to information for decision making at the second, to knowledge for management at the third, and ultimately to wisdom for peace at the top rung at which conflict is resolved. With respect to the type of application that is investigated, each chapter is designated according to the highest rung reached in the knowledge ladder.

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_1

Keywords Conflict resolution · International Conferences on Water Resources and Environment Research (ICWRER) · Knowledge ladder · Systems thinking · Water resources management

1.1 Overview of the International Conferences on Water Resources and Environment Research (ICWRER)

During the summer of 2013, extensive flooding took place within major river basin systems in Europe. In early June of that year, the mighty Rhine River was starting to overflow its banks in the German City of Koblenz, strategically situated at the confluence of the Moselle and Rhine Rivers. The knife-shaped headland called the "Deutsches Eck" or "German Corner" cuts into these bodies of water at exactly the point where the Moselle joins the Rhine on its long journey to the North Sea. This historical spot is adorned with a spectacular statue of Kaiser Wilhelm I on horseback, flags of Germany and its states, a park and walkways along the shoreline which were threatened to be submerged. Opposite the Deutsches Eck, situated at the top of a steep cliff on the east side of the Rhine River is the impenetrable Ehrenbreitstein Fortress, keeping close guard over Koblenz and the important river navigation system below. Barges and cruise ships plying the Rhine looked like small toy boats from above. Koblenz is truly a fitting location in which to convene a first-class international conference dealing with water and the environment (Figs. 1.1 and 1.2).

Fig. 1.1 Deutsches Eck from the Ehrenbreitstein Fortress looking westwards to where the Moselle River (*background*) joins the Rhine River (*foreground*) at Koblenz, June 2nd, 2013

Fig. 1.2 Viewing eastwards across the flooding Rhine River at the Ehrenbreitstein Fortress, June 4th, 2013

From June 3rd to the 7th, 2013, a timely international meeting called "Water and Environmental Dynamics: 6th International Conference on Water Resources and Environment Research (ICWRER 2013)" was held in Koblenz at the Rhein Mosel Halle located along the swiftly flowing Rhine River. About 350 people participated in ICWRER 2013 from exactly 50 countries located in every continent except Antarctica. After a reviewing process, a total of 438 papers were accepted for presentation in Koblenz: 302 were orally delivered by authors while 136 were displayed as posters. In attendance were world renowned scientific researchers, practitioners, government officials, students and consultants. At the Opening Ceremony, Joachim Hofmann-Göttig, Mayor of Koblenz, Blanca Jiménez Cisneros, Director of the UNESCO Division of Water Sciences and Secretary of the International Hydrological Program (IHP), State Secretary Michael Odenwald, Federal Ministry of Transport, Building and Urban Development of Germany, Minister of State Ulrike Höfken, Ministry for Economy, Transport, Agriculture and Viticulture of the State of Rhineland-Palatinate, and Dr. Johannes Cullmann, Conference Chair, and other officials warmly welcomed the conference attendees and stressed the great import of topics to be addressed at the gathering. The conference banquet was held at the imposing Electoral Palace, which was separated from the Rhine River by a beautiful garden where tasty hors d'oeuvres and refreshing Moselle wine were served prior to the main dinner in the ornate Palace at which two outstanding international scientists were awarded the ICWRER Lifetime Achievement Award: Professor Gerd H. Schmitz from the Dresden University of Technology and

Professor Graeme Dandy from the University of Adelaide. Professor Kaoru Takara from Kyoto University introduced the next ICWRER conference which he will host in Kyoto, Japan's cultural heartland, in the summer of 2016.

The succession of ICWRER conferences originated at the University of Waterloo in 1993 with the conference entitled "Stochastic and Statistical Methods in Hydrology and Environmental Engineering" held in honor of the late Professor T.E. Unny. Subsequent to this conference, papers that underwent a thorough reviewing process were published by Kluwer in four edited books (Hipel 1994a, b; Hipel and Fang 1994; Hipel et al. 1994). The next six conferences convened in Kyoto (1996), Brisbane (1999), Dresden (2002), Adelaide (2008), Quebec City (2010) and Koblenz (2013) all adopted the more encompassing title of ICWRER. As just mentioned, the 7th conference having the title of ICWRER will be hosted in Japan in 2016. All of these highly successful conferences were attended by more than 300 attendees from around the globe with the highest registration being about 800. A detailed history of the ICWRER conferences is provided by Hipel et al. (2013a) in an introductory paper to articles initially presented at ICWRER 2010 in Quebec City and subsequently published in the Canadian Water Resources Journal. The authors of this current overview chapter are members of the ICWRER Steering Committee chaired by K.W. Hipel.

As stated by Cullmann (2013) in the Foreword to the ICWRER 2013 conference proceedings: "The ICWRER conference series provides an independent platform for scientists in the fields of hydrology, environmental research, aquatic ecosystem research [to present and discuss their work]. The focus of the 6th conference was set on fostering an integrative understanding of water and the environment. It brought together physical, biological, chemical, statistical, socioeconomic and technical expertise to discuss solutions for transient environmental boundary conditions". The main categories of papers included in the conference proceedings consisting of 665 pages are climate change; hydrological extremes; management; modelling, methods and mathematics; and sediments. In addition to the proceedings, two edited books containing selected papers presented at ICWRER 2013 were published by Springer: "Sediment Matters—The Challenges", edited by Heininger and Cullmann (2015), as well as "Conflict Resolution in Water Resources and Environmental Management", edited by Keith W. Hipel, Liping Fang, Johannes Cullmann and Michele Bristow, for which this chapter constitutes the introduction and overview.

In order to proactively manage water resources challenges such as flooding in Europe during 2013, an integrative and adaptive approach to water and environmental management is required which takes into consideration the value systems (Keeney 1992; Bristow et al. 2014) of affected stakeholders such as navigation, industrial, agricultural, domestic, recreational and environmental interests (Hipel and Fang 2005; Hipel et al. 2008a, b, 2009, 2013b; International Joint Commission 2009; GWP and INBO 2009; National Research Council 2004). Because these interest groups view the problem and solutions thereof through different lenses, conflict is bound to arise. Accordingly, conflict resolution is of great import in water and environmental management in order to reach fair and sustainable resolutions. Moreover, the fact that the fields of water resources and environmental management span both the societal realm, in which people and organizations interact, and the physical world which sustains all human activities, makes these conflicts particularly complex and challenging to solve. For instance, when large-scale water diversions take place across political jurisdictions, conflicts may ensue among stakeholders within and across regions, while the water transfers may cause severe damage to sensitive ecological systems (Hipel et al. 2008b). Therefore, to arrive at realistic and fair resolutions, one must take into account not only the economics and politics of the situation but also the water quantity and quality changes that may occur within the altered hydrological system as well as the ecosystems contained therein. When the effects of climate change, and the closely connected activities of energy production and usage are also considered, the complexity of the problem becomes even greater and messier.

The objective of this edited book is to present some of the latest ideas in conflict resolution in water resources and environmental management by scientists and engineers who originally presented their research on this topic at ICWRER 2013 and subsequently submitted their expanded papers for review and possible publication in this book. The purpose of this overview chapter is to put into perspective the range of interesting papers published on this topic in the upcoming chapters. In the next section, the main research contributions contained in the chapters are highlighted, while in Sect. 1.3 the research is compared according to research themes and application areas. Finally, Sect. 1.4 provides valuable insights and guidance for continued research.

1.2 Research Contributions

Shortly after the completion of ICWRER 2013, an announcement was posted on the conference website in which authors who participated in the conference were given the opportunity to submit high quality papers falling under the theme of this edited volume for possible publication. The response to this solicitation of papers was very good and each paper that was received underwent a thorough reviewing process. In fact, the time taken to review the papers and subsequently revise them, usually twice per paper, was just over one year. Ultimately, fifteen papers were accepted for publication as chapters in this book.

The goal of this section is to outline the rich range of contributions contained in the papers appearing in this volume as summarized in Table 1.1. As can be seen in this table, the fifteen accepted papers are listed in the left column as Chaps. 2–16 in the edited book. The second column from the left provides the names of the authors of the chapters. The two columns on the right in Table 1.1 contain a summary of the main contributions appearing in each chapter according to methodologies and associated capabilities (second column from the right) and the case study presented along with connected comments regarding general applicability of this type of application.

The chapters in the book are categorized into four main parts, as shown in Table 1.1. Specifically, the chapters contained in Part I in this book are mainly concerned with Management and Evaluation. Consider, for example, Chap. 2,

Table 1.1 Main contributions of authors of the chapters according to methodologies and applications within four domains of water resources and environmental management

Chapters	Authors	Main contributions	
		Methodologies	Case study
		Capabilities	General applicability
Part I: Management and evaluation			
Chapter 2: Mitigating dam conflicts in the Mekong River Basin	T.B. Wild, D.P. Loucks (2015)	Daily simulation model of flow and sediment in a water network of reservoirs and channels	Hydropower development in the Mekong/Lancang River Basin, Cambodia
		Predicts in relative terms accumulation and depletion of sediment in river channels and reservoirs over time and space under different operating and sediment management policies	Screening of sediment management options: identifies relative tradeoffs between hydropower production and flow and sediment regime alteration
Chapter 3: Groundwater management instruments and induced second-order conflicts: the case of the Paraíba River Basin, Brazil	Z.M.C.L. Vieira, M.M.R. Ribeiro (2015)	Multiple criteria evaluation; Graph Model for Conflict Resolution	Groundwater aquifers in the Paraíba River Basin, Brazil
		Identifies unintended consequences of water quality guidelines, water permits, and bulk water charges and their potential for inducing second order conflicts	Avoidance/mitigation of second-order conflicts in groundwater management: recommends improved monitoring capacity, reduced supply failures and tariffs, and raising awareness in groundwater users to increase acceptance of management measures

(continued)

Table 1.1 (continued)

Chapters	Authors	Main contributions	
		Methodologies	Case study
		Capabilities	General applicability
Chapter 4: Paying to conserve watershed services in Pangani River Basin, Tanzania	M.C.S. Lalika, P. Meire, Y.M. Ngaga (2015)	Field Studies: hydrological data collection through site visits; socio-economic data collected by documentary review and structured questionnaires	Ecosystem services valuation of the Pangani River Basin, Tanzania.
		Findings: actual water sold is lower than billable water due to water leakages and/or theft; actual revenue is lower than projected revenue causing water supply problems	Watershed management: enhances sustainable water flow through integrated payment for watershed conservation
Chapter 5: Economic valuation for decision making on the protection of water sources	H. Castanier (2015)	Natural Resources Valuation: Contingent Valuation Method utilizing in-person surveys	Protection of natural water sources for the drinking water supply of the city of Quito, Ecuador
		Elicits individuals' willingness-to-pay for environmental resources with the use of multiple scenarios of water sources protection.	Watershed protection: takes into account the economic value of water in its natural state to prevent land degradation and water pollution

(continued)

Table 1.1 (continued)

Chapters	Authors	Main contributions	
		Methodologies	Case study
		Capabilities	General applicability
Part II: Global, trans-boundary and international dimensions			
Chapter 6: Is water really a scarce resource? Initiating entrepreneurship for global clean water supply: implications of a global economic policy on water security and entrepreneurial technology strategy	A. Presse (2015)	Three-level model (1: sufficiency, 2: efficiency, 3: equivalence) for global economic policy development to assure purchasing power for drinking water to survive	Global auctioning process to enable entrepreneurs to provide water and payouts to ensure that everyone can pay for water
		Develops incentives for global entrepreneurship and the application of the latest technologies	Global response to climate change and water insecurity: access to clean water can be secured through a per-capita-payout of the scarcity rent of the atmosphere
Chapter 7: Trans-boundary river basin management: factors influencing the success or failure of international agreements	H. Mianabadi, E. Mostert, N. Van de Giesen (2015)	Review of significant challenges of trans-boundary river basin management; overview of primary factors that can potentially increase conflict among riparian countries	Examination of Indus River Agreement (1960), Nile River Agreement (1959), and Euphrates River Agreement (1987)
		Points out uncertainty in hydrological conditions, impacts of climate change, lack of comprehensive water laws, ambiguity in international water laws, power asymmetry and non-integrated water management	Trans-boundary water management: design of resilient water treaties to decrease the likelihood of the collapse of international water agreements and potential for conflict among riparian countries

(continued)

Table 1.1 (continued)

Chapters	Authors	Main contributions	
		Methodologies	Case study
		Capabilities	General applicability
Chapter. 8: Drinking water treatment and supply in developed countries in 2045—where will we be?	P.M. Huck (2015)	Descriptive analysis of technical, institutional and human aspects of development and maintenance of robust systems	Adequate and secure drinking water supply infrastructure in developed countries
		Highlights future trends affecting the robustness of the following: (1) the source, (2) treatment, and (3) distribution	Provision of public water supply: decision makers need to consider changing environments as well as water consumers and their expectations
Chapter 9: The Keystone XL Pipeline dispute over transferring bitumen from the Alberta oil sands to US refineries	S. Payganeh, A. Obeidi, K.W. Hipel (2015)	Conflict description of environmental, political and economic dimensions; Graph Model for Conflict Resolution	Construction of the Keystone XL pipeline from the Alberta oil sands, Canada, to southern part of the United States
		Investigates a real-world conflict through a systems methodology so that stakeholders gain strategic insights into its resolution	Resolution of conflict among economic and environmental issues: uncovers pathways to equilibrium states that are desirable for all participants

(continued)

Table 1.1 (continued)

Chapters	Authors	Main contributions	
		Methodologies	Case study
		Capabilities	General applicability
Part III: Consensus-building, bargaining, and negotiations			
Chapter 10: A data mining tool for planning sanitary sewer condition inspection	R. Harvey, E. McBean (2015)	Data Mining: Classification And Regression Tree (CART) methodology	Assessment of sanitary sewers in Guelph, Ontario, Canada
		Predicts pipe condition (good vs poor condition) with an overall accuracy of 76% and effectively identifies individual pipes for future rounds of inspection	Proactive management of aging sewer pipes: enhances understanding of life-cycle degradation of pipes and serves as a consensus-building tool for the allocation of funds towards future pipe inspection
Chapter 11: Bargaining under uncertainty: a Monte-Carlo Fallback Bargaining method for predicting the likely outcomes of environmental conflicts	K. Madani, L. Shalikarian, A. Hamed, T. Pierce, K. Msowoya, C. Rowney (2015)	Monte-Carlo selection with Fallback Bargaining (FB): Unanimity FB, q-Approval FB, and FB with impasse	Water export problem in California's Sacramento-San Joaquin Delta (US)
		Ranks alternative plausible outcomes of a bargaining game, and further determines the ranking robustness	Decision analysis of two-participant, two-criteria decision making, which can be extended to multi-participant, multi-criteria problem: finds acceptable compromises so that decision makers can reach an agreement

(continued)

Table 1.1 (continued)

Chapters	Authors	Main contributions	
		Methodologies	Case study
		Capabilities	General applicability
Chapter 12: A decision support system for solving the conflict between human and environment	J. Jiang, H. Xu, Y. Jiang (2015)	Decision Support System: Matrix Representation for Conflict Resolution	Garrison Diversion Unit (GDU) conflict among the United States of America (US), Canada and the International Joint Commission (IJC)
		Deals with complex strategic conflicts with three-degree preference relations (indifference, strict preference, strong preference)	Conflict analysis of environmental disputes where stakeholders have different intensities of preferences: predicts resolutions that are strongly stable
Chapter 13: CAPE WIND: offshore renewable energy conflict	M.J. Larson (2015)	Stakeholder Analysis; Turning Point Matrix	Cape Wind conflict regarding the first offshore wind farm in the United States of America
		Exhibits negotiation dynamics, dimensions of power, trigger actions and major turning points to study complex multilateral conflicts	Control of multi-party negotiations through psychological factors: emphasizes the need to address public opinion from the start of negotiations

(continued)

Table 1.1 (continued)

Chapters	Authors	Main contributions	
		Methodologies	Case study
		Capabilities	General applicability
Part IV: Ecological and socio-economic impacts			
Chapter 14: Quantitative evaluation of hydromorphological changes in navigable waterways as contribution to sustainable management	N. Cron, I. Quick, S. Vollmer (2015)	VALMORPH: eVALuation of MORPHology	Evaluation of changes of the hydromorphological characteristics for the German part of the inland Elbe River (from the Czech border 586 km)
		Detects and evaluates changes of the hydromorphology of rivers and their floodplains	Evidence-based decision making and prioritization of water resources management options: takes into account integrative and international consideration of river basins
Chapter 15: Agricultural water resources limitations and their effects on the socioeconomic conditions of wheat farmers: a case study of Maku City in Iran	P. Salimzadeh, K. Kalantari (2015)	Factor Analysis: data collection through questionnaires	Water resources limitations and its effects on farmers in Maku City, Iran
		Findings: Farmers perceive that limitations of water resources are mainly due, in order of dominance, to atmospheric and natural conditions, patterns of water resources utilization, challenges of water resources management, and patterns of land utilization. Farmers perceive, in order of dominance, economic effects, social effects and environmental effects due to water resources limitation	Water resources management and human development: identifies significant challenges regarding agricultural water resources and effects of these challenges on farmers; assists planners and policy makers to develop appropriate strategies to improve resource use and for farmers to raise awareness of optimal allocation of resources

(continued)

Table 1.1 (continued)

Chapters	Authors	Main contributions	
		Methodologies	Case study
		Capabilities	General applicability
Chapter 16: Impact of climatic and anthropogenic factors on groundwater irrigation in South India	T. Mohanasundari, R. Balasubramanian (2015)	Regression analysis: econometric analysis	Groundwater aquifers in the Tamil Nadu state in South India
		Estimates: (1) depth of water table level, (2) area irrigated per well as an indicator of water availability in wells and efficiency in use of irrigation water, and (3) private and social costs of groundwater use	Groundwater management: addresses the major challenge to stabilize aquifers which exhibit hydraulic imbalance in light of climate change; supports necessary and appropriate policies to ensure groundwater recharge and fair use

which is entitled “Mitigating Dam Conflicts in the Mekong River Basin”. As can be seen in the second column from the right, the key methodology is a simulation model for producing daily flows and sediments in a water network of reservoirs and channels. This can be employed to predict the accumulation and depletion of sediment in river channels and reservoirs over time and space under a range of operating and sediment management policies. The entries in the right column of Table 1.1 for Chap. 2 indicate that hydropower development in the Mekong River Basin in Cambodia constitutes the case study contained in the chapter. The Mekong River originates in China where it is called the “Lancang River”. In general, as stated in the far right column, this approach can be used to identify relative tradeoffs between the production of hydropower and the changing of the sediment regime. One of the authors of this chapter, D.P. Loucks, is a pioneer in taking a systems approach to tackling complex water resources management problems as evidenced by his landmark books (Loucks et al. 1981; Loucks and van Beek 2005). Starting with the pioneering book of Maas et al. (1962), other books that take a systems approach (Sage 1992; Jamshidi 2009) to investigate problems in water resources management include contributions by Hipel and McLeod (1994), Jain and Singh (2003), Haimes (2009), Simonovic (2009, 2011), and Chang (2011).

The second main part in this book is called “Global, Trans-boundary and International Dimensions”, as indicated in Table 1.1. As an illustration of a chapter in this part, take a look at Chap. 6 in which the author, A. Presse, poses the question “Is Water Really a Scarce Resource” as part of the title for the chapter. He declares that the answer to the problem is no if individuals have sufficient purchasing power to buy water. To accomplish this, Presse develops a three-level model for a global economic policy to ensure that everyone has sufficient purchasing power to obtain drinkable water for survival purposes. He proposes incentives for global entrepreneurship and the utilization of the latest technologies. More specifically, he puts forward the idea of a global auctioning process to enable entrepreneurs to provide water and payment to individuals to make sure that everyone can afford water. He maintains that access to clean water can be secured via a per-capita payout obtained from the scarcity rent of the atmosphere.

The four chapters appearing under Part III in Table 1.1 address the topic of “Consensus-building, Bargaining and Negotiation”. As an example of one of the chapters, examine Chap. 10 on “A Data Mining Tool for Planning Sanitary Sewer Condition Inspection” written by Harvey and McBean. Within this chapter, the authors utilize data mining methodologies to predict pipe conditions. Their case study deals with the assessment of sanitary sewers in Guelph, Ontario, Canada. In fact, the proactive management of aging sewer pipes improves the understanding of the life-cycle degradation of pipes and acts as a consensus-building tool for the allotment of funds towards future pipe inspections.

The final main part of the book on “Ecological and Socio-Economic Impacts” contains three chapters. Chapter 14, for instance, which was authored by N. Cron, I. Quick and S. Vollmer, deals with “Quantitative Evaluation of Hydromorphological Changes in Navigable Waterways as Contribution to Sustainable Management”.

A methodology called VALMORPH (eVALuation of MORPHology) is developed for the detection and evaluation of changes in the hydromorphology of rivers and their floodplains. This approach is applied to the German part of the inland Elbe River. This procedure could be used in evidence-based decision making and the prioritization of water resources management options which takes into account integrative and international considerations of river basins.

1.3 Research Themes and Application Areas

The aim of this section is to reveal further the wealth of knowledge contained in the subsequent fifteen chapters in this book by classifying them according to the types of applications and where they stand in the decision-making process with respect to the ultimate goal of conflict resolution and attainment of wisdom. As indicated on the far right column in Table 1.1, each of the chapters contains an application which falls under an application area shown on the left in Fig. 1.3. Furthermore, the decision-making component contained in each chapter reaches a rung in the knowledge ladder displayed on the right in the same figure. Within Fig. 1.4, the contents of the fifteen chapters are plotted according to the application area and the knowledge ladder whereby these two categorizations appear as the horizontal (abscissae) and vertical (ordinates) axes, respectively.

Consider now the wealth of information about this book displayed in Fig. 1.4. When examining the application areas listed along the horizontal axis (also refer

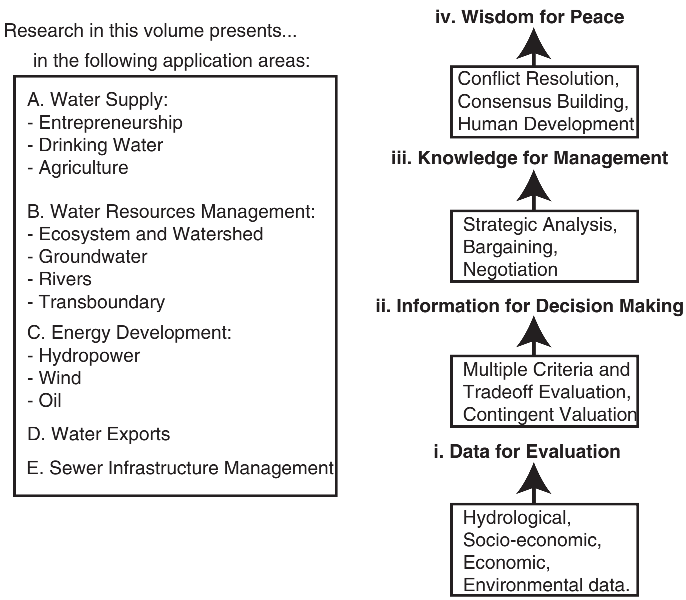

Fig. 1.3 Research themes ascending the knowledge ladder towards conflict resolution

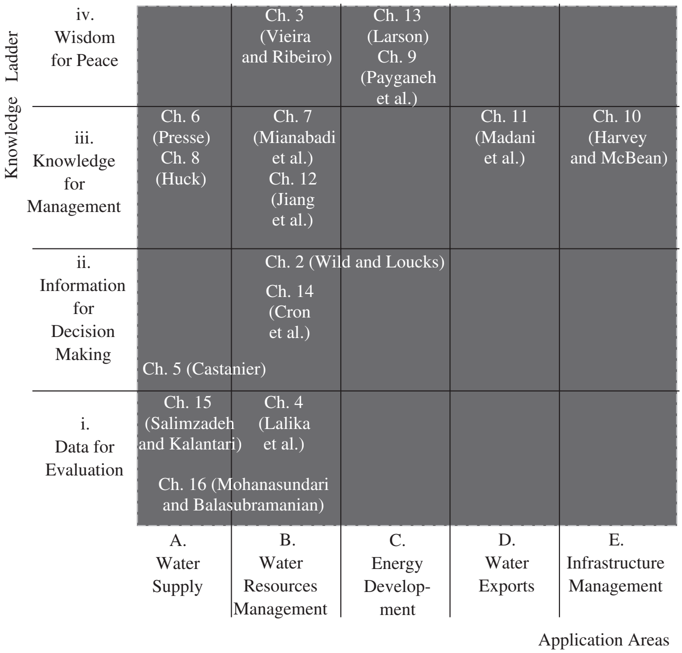

Fig. 1.4 Mapping of chapters to application areas and knowledge ladder rungs

to the right column in Table 1.1), one finds that 11 of the 15 later chapters focus on water supply and water resources management. As can be seen, the other three kinds of applications appearing in this book deal with energy development, which of course is closely connected to water and environment management, water exports and sewer infrastructure management.

When one inspects the vertical axis in Fig. 1.4, one discovers that there are at least three chapters in which each rung in the knowledge ladder is attained. For example, for the applications furnished in Chap. 5 (water supply application), as well as Chaps. 2 and 14 (water resources management applications) the second rung labelled as “rung ii. Information for Decision Making” is reached. Notice that as one climbs the knowledge ladder one first evolves from crucial Data needed for Evaluation (both physical systems and societal systems data) to Information for Decision Making for which multiple criteria and tradeoff evaluation and contingent valuation may be utilized with the basic data as input. One can then progress to the third rung, Knowledge for Management, at which strategic analyses such as bargaining and negotiation may be employed in a specific case study. At the top of the ladder, methods such as conflict resolution and consensus building in group decision making may be applied to a real world dispute in order to achieve a fair and sustainable resolution, which is called Wisdom for Peace at rung iv at the summit of the vertical axis in Fig. 1.4 and the top of the knowledge ladder on the right in Fig. 1.3. As one climbs the knowledge ladder, findings from one rung are lifted to the next one in order to eventually invoke wise decisions within multiple participant-multiple objective situations in which wise, fair and sustainable decisions are made with solid data as the foundations at the first rung.

To illustrate how the metaphor of a ladder for decision making can be highly informative when reading a specific chapter in this book or investigating a particular water resources problem that is of interest to a person, an explanation is now provided for a chapter listed at each rung in the ladder in Fig. 1.3. An application occurring at the first rung is provided by Lalika, Meire and Ngaga in Chap. 4. As is explained in Table 1.1, these authors investigate the valuation of ecosystem services in the Pangani River Basin in the East African nation of Tanzania. In field studies valuable data are obtained for both the physical and societal aspects of the problem: hydrological data collection via site visits and socio-economic data obtained via structured questionnaires and reviewing documents. The authors discover that the actual water sold is lower than billable water due to water leakages and theft. Hence, the actual revenue obtained is lower than the projected revenue, which in turn causes water supply management problems.

An example of an application that reaches the second rung in Fig. 1.4 is supplied in Chap. 5 in which Castanier studies the protection of natural water sources for the drinking water supply in the city of Quito, Ecuador. The author used a contingent valuation method to ascertain individuals' willingness-to-pay for environmental resources, which takes into account the economic value of water in its natural state to prevent land degradation and water pollution.

An interesting example of an application in which the third rung in the knowledge ladder is attained is furnished by Madani et al. in Chap. 11. The case study involves a water export problem in the Sacramento-San Joaquin Delta in the American state of California. The authors employ Monte-Carlo selection with Fallback Bargaining to discover acceptable compromises to permit decision makers to reach an agreement.

Within Chap. 3, Vieira and Ribeiro address conflicts arising over the management of groundwater aquifers in the Paraíba River Basin in Brazil using multiple criteria evaluation and the Graph Model for Conflict Resolution (GMCR) (Fang et al. 1993). In fact, GMCR is also utilized in Chaps. 9 and 12 in the book. In Chap. 3, the Brazilians would like to avoid or mitigate what they call second-order conflicts in groundwater management by having improved monitoring capacity, reduced supply failures and tariffs, and increased awareness of the groundwater users. All of these measures are founded upon having reliable data, knowledge and information obtained at lower rungs in the knowledge ladder displayed on the right in Fig. 1.3.

1.4 Key Insights and Future Directions

Because water and the environment are of direct concern to a wide range of interest groups, conflict inevitably arises whenever these important issues come into play. In Chap. 3, for instance, Vieira and Ribeiro investigate conflict connected to groundwater resources in the Paraíba River Basin in Brazil. Within Chap. 9, Payganeh et al. examine conflict connected to the proposed building of the controversial Keystone XL Pipeline to ship bitumen from the Alberta oil sands in Canada to refineries in the Gulf Coast of the United States. As is broadly recognized, energy problems are often closely linked to environmental and water issues. In fact, having a good energy policy means having a sound environmental policy and vice versa.

As noted in Sect. 1.1, the purpose of this edited book is to present some of the latest findings in conflict resolution and environmental management with applications to a fascinating array of problems. Section 1.2 puts the many research contributions into perspective as summarized in Table 1.1. Since conflicts over water and the environment are usually interconnected to other issues, one may wish to take a system of systems approach when addressing a particular dispute (Hipel et al. 2009, 2010; Bristow et al. 2012). Moreover, one should adopt an integrative and adaptive approach to water and environmental governance that specifically recognizes the conflicting value systems of stakeholders (Keeney 1992; Bristow et al. 2014), including nature and future generations even though they are not present at the bargaining table (Hipel et al. 2008b). Additionally, as explained in Sect. 1.3 and depicted on the right in Fig. 1.3, one can envision decision making in water and the environment as ascending the knowledge ladder. As can be seen, sound decisions made higher up on the ladder must be based on having reliable physical and societal systems data available at the first rung in the ladder. In other words, good fieldwork is required to understand how the physical systems work and how the value systems of stakeholders can affect how interconnected decisions among them ultimately determine the outcomes to disputes. By adhering to evidence-based decision making, stakeholders are more likely to implement solutions that are reached. If they believe that a given resolution is fair by attempting to satisfy the conflicting interests of the various groups based on sound data, the resolution will be more durable.

As the saying goes, good practice means having good theory. The various systems methodologies presented in the upcoming chapters are as listed in the third column of Table 1.1. The case studies mentioned in the fourth column of Table 1.1 demonstrate how these methodologies can be utilized in practice with the applications that are investigated as well as in general. These case studies, for which a categorization is given on the left in Fig. 1.3, can be effectively addressed for enhancing decision making by keeping in mind the knowledge ladder shown on the right in Fig. 1.3. Figure 1.4 displays the highest rung that is reached for the applications given in each of the subsequent 15 chapters. Both practice and theory need a solid foundation of good data, whilst keeping in mind that one is ultimately aiming to climb up to higher rungs on the knowledge ladder and aspire towards wisdom for peace. At the base, however, are good data which are a necessity for making sound decisions.

Acknowledgments The Editors would like to express their appreciation to the hosts and organizers of ICWRER 2013, held in Koblenz from June 3rd to 7th, at which the initial versions of chapters contained in this special edited volume were originally presented. As mentioned in Sect. 1.1, this highly successful conference was ably chaired by Dr. Johannes Cullmann with the dedicated assistance of Ms. Ana Maria Conde Corral from the German Federal Institute of Hydrology, members of the Scientific Steering Committee for ICWRER 2013, and members of the ongoing ICWRER Steering Committee chaired by K.W. Hipel and co-chaired by G. Dandy (all authors of this introductory chapter are members of this committee). Kind acknowledgement is also directed to Dipl.-Ing Michael Behrendt, Director General of the German Federal Institute of Hydrology. They are also grateful to the authors of the papers for expanding and revising their articles after the conference based on feedback obtained at their presentations, submitting their extended papers for review, and then appropriately revising their papers following helpful suggestions furnished by the reviewers. The Editors are indebted to the many anonymous referees who devoted their valuable time and expertise to carefully read the papers and provide thoughtful comments for enhancing them. Dr. Michele Bristow kindly coordinated the reviewing and revising process of the chapters in arriving at this high quality, fully-refereed book publication. Finally, the Editors also wish to thank Dr. Stephan Klapp from the Environmental Sciences Division of Springer as well as other Springer personnel for their work in the planning and execution of the publication of this book.

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Part I
Management and Evaluation

Chapter 2
Mitigating Dam Conflicts in the Mekong River Basin

Thomas B. Wild and Daniel P. Loucks

Abstract The Mekong/Lancang River Basin is undergoing a period of rapid hydropower development, with plans to construct over 100 dams in the next several decades. These dams may alter the river's natural flow and sediment regimes, which could significantly degrade the exceptional biodiversity and productivity of the basin's ecosystems. Sediment that is trapped in reservoirs will be unavailable to support the basin's geomorphology and habitats, and by reducing reservoir water storage capacity may decrease hydropower output and reliability. This paper illustrates how alternative dam location, design and operation may have the potential to reduce reservoir sediment trapping. This paper describes the simulation model used to identify alternative siting, design and operating options for two planned dams in Cambodia: Sambor on the Mekong River and Lower Se San 2 on a tributary of the River. Lower Se San 2 Dam is particularly important with respect to biodiversity and ecological productivity. Sambor Dam could prevent significant quantities of sediment from reaching Tonle Sap Lake and the Vietnam Delta, two critically important features of the river basin. Results from daily simulations of water and sediment flows show the extent to which sediment management practices could reduce the adverse impacts of reservoir sediment trapping if conducted in an environmentally friendly manner, as well as the loss in hydropower production resulting from those practices.

Keywords Dams · Mekong River · Reservoir sediment management

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_2

2.1 Introduction

The Mekong/Lancang River flows from the Tibetan Plateau through the Upper Mekong Basin in China (where it is called the *Lancang Jiang*) to the Lower Mekong Basin (LMB), draining parts of Myanmar, Lao PDR, Thailand, Cambodia, and Vietnam. The River discharges into the South China Sea. It has remained largely unaltered for much of its history. Recently, the construction of dams on the mainstream Lancang River, along with dams on tributaries of the Mekong River in the LMB, are signaling future changes in the course of development of this incredibly biodiverse river basin.

The Mekong basin is home to more than 60 million people. Many depend directly on the river and its tributaries as a source of income and food security (MRC 2010). The river basin is second in biodiversity to the Amazon River Basin (MRC 2010). The LMB has an estimated hydropower potential of 30,000 MW, of which only 10 % has been developed to date (MRC 2010). By 2030, the construction of 62 dams, including 6 on the Lancang River and 56 on LMB tributaries, is expected to be completed (MRC 2011b). Plans exist for a total of 134 dams to be eventually built in the LMB. The extent of river basin development planned to occur over a relatively short span of time warrants an evaluation of the potential impact of the planned development on the temporal and spatial distribution of water and sediment, both of which play critical roles in shaping the river system and maintaining its productivity.

The river's 795,000 km^2 watershed discharges about 460 km^3 of water each year. The climate of the Mekong Basin is controlled by the Monsoon that produces annual wet and dry seasons of approximately equal length (MRC 2005). The Mekong River is among the world's largest in terms of length and sediment load, delivering approximately 160 million metric tons (Mt) of suspended sediment per year into the South China Sea (Milliman and Meade 1983).

A major flow and sediment contribution to the mainstream Mekong River, shown in Fig. 2.1, is from the Se San, Sre Pok and Se Kong (3S) River Basins. The 3S basins have a contributing watershed area of 78,650 km^2, covering approximately equal parts of Cambodia, Lao PDR and Vietnam. The 3S Rivers have a combined discharge of about 17–20 % of the Mekong River's annual runoff, and likely produce a similar fraction of the LMB sediment load (Kondolf et al. 2011; Sarkkula et al. 2010; ICEM 2010), as well as provide habitats for migrating fish and birds. The 3S Rivers provide fish spawning and breeding grounds to over 40 % of Mekong fish species (Baran et al. 2013).

Half of the Mekong basin's annual sediment load is likely generated in the Upper Mekong Basin (China) and the remaining half in the LMB (Clift et al. 2004). The construction of dams on the Lancang River in China is expected to trap much of the 80 Mt generated annually there (Lu and Siew 2006; Fu and He 2007; Kummu and Varis 2007; Kondolf et al. 2014), with significant trapping potential at dams in the LMB as well (Kummu et al. 2010; Kondolf et al. 2014). Sediment trapping is not just an issue in the Mekong Basin. Worldwide, reservoir storage capacity is declining due to sedimentation at an estimated average rate of 0.5–1 % per year (Mahmood 1987;

Fig. 2.1 Se San, Sre Pok, and Se Kong (3S) tributary basins to the Mekong River, showing current and future reservoir locations. The *red arrow* indicates the proposed location of the Lower Se San 2 (LSS2) Dam site, whereas the *red dashed line* indicates the proposed location of Sambor Dam on the mainstream Mekong River. Modified from Wild and Loucks (2014a).

White 2001). More than 50 % of sediment flux in regulated river basins may be getting trapped in reservoirs or other artificial impoundments (Vörösmarty et al. 2003).

Sediments that are trapped in reservoirs are unable to perform two vital functions downstream. First, sediment is needed to preserve the geomorphologic makeup (or physical structure) of the river system downstream that directly influences habitat quality and availability (Power et al. 1996). In the Mekong basin, this includes the Vietnam Delta, wetlands, the near-shore ocean ecosystem, and floodplain ecosystems. Second, fine sediments (e.g., clay) adsorb and transport nutrients, particularly phosphorus, which play an important role in primary production and floodplain fertility (Baran and Guerin 2012). In a flood pulse-driven system such as the Mekong River, the exchange of sediment and nutrients between the river and floodplains is responsible for the production of the majority of riverine biomass (Junk et al. 1989; Sverdrup-Jensen 2002; Lamberts 2006). In this study, sediment passage serves as a surrogate measure for the potential for ecosystem productivity.

Aside from geomorphologic and nutrient transport issues, sediment accumulation is undesirable from an economic perspective because it reduces reservoir storage capacity, which shortens the reservoir's useful life and flow of future benefits (e.g., power production and flood control); and increases operations and maintenance costs (Morris and Fan 1998). If a dam fills with sediment and is left in place, the dam site, of which there are a limited number, may be permanently lost for use by future generations, and can become a safety hazard Annandale (2013). Conversely, removal of a silted dam can be extremely costly and can lead to the release of large quantities of potentially environmentally harmful accumulated sediments (Baran and Nasielski 2011).

Thus far, relatively little research has been conducted in the LMB regarding the potential impact of reservoir operations on the sediment balance. Previous studies found the potential for 51–96 % of suspended sediment to be trapped throughout the Mekong basin (Kummu et al. 2010; Kondolf et al. 2014), with as much as 80 % trapping of suspended sediments in 3S basins reservoirs (Wild and Loucks 2014b). This study evaluates measures that could be taken to reduce such significant sediment accumulation in reservoirs, including alternatives to the siting (location), design (size of reservoir, and availability of mid- and low-level outlets), and operations (e.g., sediment flushing operations) of dams. We identify sediment management practices that are feasible at different planned dam sites; evaluate whether these techniques can improve reservoir sediment outflows without damaging the environmental features the practices are attempting to preserve; and evaluate what losses in typical reservoir function, primarily hydropower production, may be necessary to achieve the improved sediment passage.

Decision makers in the LMB are facing an extremely difficult challenge in shaping the development paths of their respective countries, especially in the less developed nations of Lao PDR and Cambodia, where rapid economic development is internally viewed as imperative. Water is often the most abundant, valuable natural resource in LMB countries, which makes hydropower a particularly attractive energy option. This energy could nurture economic development and be exported for profit. At the same time, 47 %–80 % of the populace relies on fish and other aquatic animals as a primary protein source (Hortle 2007) and 50 % rely on these animals for income (MRC 2010). The fish are directly dependent on the health of the riverine ecosystems that hydropower production could adversely impact. Each country's fate will be determined in part by the decisions taken with respect to these tradeoffs. Rather than arguing no dams should be built, the sediment management options discussed in this paper acknowledge that dams will be built, but suggest that more benign (with regard to sediment) alternatives to many of the currently proposed dams exist and should be considered.

This paper examines sediment management alternatives as a means of reducing conflicts, hopefully providing an acceptable outcome for all stakeholders in the basin. We are concerned about all the dams being constructed or planned in the basin, but for the purposes of this discussion we will focus on Lower Se San 2 (LSS2) Dam in the 3S basins and Sambor Dam on the mainstream Mekong River. Both are in Cambodia, but have the potential of impacting Vietnam as well.

At the LSS2 Dam site, full drawdown sediment flushing appears to be the best option for reducing sediment trapping (Annandale 2012a). The LSS2 Dam is important because it could reduce basin-wide fish biomass production by over 9 % (Ziv et al. 2012), which is the highest potential among tributary dams. Additionally, LSS2 could be constructed within the next 5 years. Thus, identification and evaluation of opportunities to increase sediment passage through the reservoir, while maintaining significant energy production at the site, is of current interest.

At Sambor Dam, both flushing and sediment bypassing could reduce sediment trapping. Sambor Dam is perhaps the most important proposed dam in the entire basin. Its proposed location at the bottom of the basin could result in sediment and nutrient reductions for two of the basin's most important features that rely on sediment: Tonle Sap Lake (in Cambodia) and the Vietnam Delta. Tonle Sap Lake is one of the most productive freshwater fisheries in the world. The Vietnam Delta produces significant quantities of rice and fish, and hence affects the lives of millions of people. Additionally, the potential for Sambor to trap significant quantities of sediment could discourage efforts to pass sediment through dams throughout the basin upstream. (The same is true of all the dams on the Se San and Sre Pok Rivers upstream of LSS2.) Finally, the proposed Sambor Dam would be the most downstream dam sited on the mainstream Mekong River, and as such would be positioned to severely disrupt fish passage, particularly for long-distance migratory species, thereby reducing LMB total fish biomass (Dugan 2008; Baran and Myschowoda 2009; Baran 2012). A natural sediment and fish bypass system, if successful, could greatly reduce the impact of Sambor Dam on the LMB fishery.

2.2 Sediment Management Options

Before discussing the sediment management alternatives for LSS2 and Sambor in more detail, it is useful to review the array of reservoir sediment management options available to better understand how sediment flushing (at LSS2 and

Sambor) and sediment bypassing (at Sambor) fit in among the range of available techniques. Annandale (2013) and Morris and Fan (1998) provide diagrams and pictures of these techniques.

A variety of options are available for managing sediment in reservoirs, and they generally fall into three categories: minimizing sediment inflow (e.g., catchment management), preventing inflowing sediment from settling by hydraulically routing sediment beyond the reservoir (sediment routing), and removing sediment after it settles (sediment removal) (Annandale 2013). Catchment management is not considered here because the goal of this study is to evaluate methods that could permit conveyance of the basin's naturally high sediment load. Sediment routing is advantageous in comparison to sediment removal in that regularly performed routing is more likely to produce reservoir sediment outflows that are consistent in timing and concentration with the natural sediment inflow regime.

Sediment routing is generally performed in one of two ways: sediment bypassing or sediment pass-through (e.g., sluicing). Both are typically performed during high flow conditions (e.g., during the monsoon season). Sediment bypassing, the option proposed for Sambor Dam, routes the sediment-laden water around the reservoir to prevent deposition in the reservoir. Sediment pass-through routes the water through the reservoir by maintaining a high sediment transport capacity. Both are implemented during high flow events when the majority of the annual sediment load is transported. Examples of bypassing include bypass tunnels (e.g., the Miwa Dam bypass system in Japan), river modification (e.g., Nagle Reservoir in South Africa), and off-channel reservoir storage (e.g., Fajardo Dam in Puerto Rico) (Annandale 2013).

Flushing can also be done in two ways: full drawdown flushing or partial drawdown flushing. Only full drawdown flushing is considered here, wherein water levels are reduced in the reservoir enough to permit free flow conditions through the low-level outlets. Flushing practices vary considerably among sites, but there exist some commonalities (Morris and Fan 1998). Flushing is typically performed during lower flow conditions, such as during the dry season or very beginning of the wet season, and for a short period of time (e.g., a week or less). From an operational standpoint, performing flushing at this time of year (1) reduces the difficulty and length of time required for drawdown because inflows are low, and (2) increases the likelihood of rapid reservoir refill (and therefore resumption of normal reservoir operations). Low reservoir water levels must be maintained during the flushing period to create high scouring velocities and retrogressive erosion. After flushing, the reservoir is refilled and normal operations are resumed. Drawdown flushing has been practiced at numerous reservoirs throughout the world (e.g., Cachi Dam in Costa Rica, Gebidem Dam in Switzerland, and Sefid-Rud Dam in Iran). Flushing is more likely than routing to adversely impact the environment, as releases typically result in a sudden increase in sediment concentration downstream. Associated impacts on fish species can be physical, chemical, and biological in nature, and are reviewed by Baran and Nasielski (2011). Concentration and duration of flushing flows have been shown to be important factors in the potential severity of flushing impacts (Newcombe and MacDonald 1991; Newcombe and Jensen 1996).

2.3 Simulating Flow and Sediment in the Mekong Basin

2.3.1 Modelling Approach

Since 1990, many hydrologic models have been used to simulate water flows in the Mekong basin (Johnston and Kummu 2012). Unfortunately, none possessed the features needed to predict in relative terms the spatial and temporal accumulation and depletion of sediment in river channels and in reservoirs under different reservoir operating and sediment management policies. Hence we developed a daily simulation model, called *SedSim*, to evaluate the performance of specific sediment management techniques (e.g., flushing, sluicing, density current venting, bypassing and dredging) in networks of reservoirs and channels (Wild and Loucks 2012). This information is used to identify the relative tradeoffs between hydropower production, and flow and sediment regime alteration, associated with these sediment management techniques. It serves as a means of identifying the more promising sediment management alternatives that can be evaluated in more detail using more detailed and hence more data-intensive models.

In this study, 21 years of average daily reservoir inflows are generated from a calibrated Soil and Water Assessment Tool (SWAT) model (MRC 2011a). *SedSim* is used to simulate sediment production, transport and trapping, as well as reservoir operations and channel routing. The data required to conduct simulations with *SedSim* were generated by other researchers and institutions. Reliable Mekong basin sediment data useful for generating daily sediment loads are not widely available (Walling 2005, 2008; Wang et al. 2011), so estimates of annual sediment production were obtained from Kondolf et al. (2011, 2014) and converted into daily sediment loads using sediment-flow rating curves (Milliman and Meade 1983; Morehead et al. 2003). In setting parameter values we benefited from the work of Walling (2009) and Wang et al. (2011). Planned reservoir and dam characteristics and operating policies were obtained from MRC (2011a, 2012) and Piman et al. (2013). Data regarding potential alternative dam configurations were obtained from Annandale (2012a, b).

2.3.2 Sediment Management Alternatives

Sediment management measures will be very difficult to successfully implement at the currently proposed dam sites of LSS2 and Sambor (Fig. 2.1). Both reservoirs, as proposed, are too long and wide (being located in floodplains) for most sediment management practices to be feasible, and thus will trap large quantities of sediment. Alternative locations and design configurations for these dams could improve their sediment passage characteristics and make sediment management possible (Annandale 2012a, b). Specifically, relocating the dams to nearby but narrower sections of the river would permit sediment flushing, as flushing is most likely to be successful in a relatively narrow reservoir whose cross-sectional dimensions approximate the dimensions of the incised channel formed during flushing. Additionally, reducing reservoir size (volume and length) not only reduces a reservoir's sediment trapping efficiency, but also increases the likelihood that sediment flushing will be feasible, given that the reservoir must be emptied of water before flushing can proceed, and must be refilled with water before normal operations can resume. Finally, building low-level outlets into the dam would enable flushing, and indeed is a requirement for flushing to be feasible at a dam site.

Figure 2.2 shows the alternative of replacing the currently proposed LSS2 dam with two smaller dams. The Lower Se San 2-II (LSS2-II) Dam on the Se San River, and Lower Sre Pok 2 (LSP2) Dam on the Sre Pok River could be frequently flushed. Figure 2.3 shows the alternative of replacing the currently proposed Sambor Dam with a smaller, narrower reservoir that could be frequently flushed and that would be fitted with a natural sediment bypass channel (using existing braided river channels on the East section of the main river channel). The sediment bypass would direct high sediment loads around the reservoir during the monsoon season and also serve as a natural fish passage system. The currently proposed Sambor Dam would prevent passage of numerous migratory fish species and submerge important fish breeding areas, resulting in potentially severe adverse impacts on the Mekong fishery (Campbell et al. 2009). While Sambor Dam as currently planned could include fish passage structures (e.g., ladders), such structures may achieve limited success compared to a natural channel, because these structures must be tailored to meet the needs of specific species, of which there are many in the lower portion of the LMB. Bypassing is assumed to occur during monsoonal flows, or those flows in excess of twice the mean annual inflow (27,600 m^3/s). During this time, the portion of flow entering the upstream end of the reservoir site in excess of 27,600 m^3/s is bypassed along with an identical portion of the suspended sediment load.

Several modeling assumptions regarding flushing and bypassing should be mentioned. Flushing at each site is assumed to proceed for 4 days, beginning around the time of year when the reservoir inflow first exceeds the mean daily unregulated inflow. This unregulated mean daily inflow rate is assumed to be the target flushing discharge rate. Flushing a reservoir with this flow rate produces a reasonable long-term sustainable storage capacity (greater than 35 %), but is not too large for reasonably-sized low-level outlets to empty the reservoir and discharge flow during flushing without ponding above the outlets. For flushing to be considered successful in a given day, the water surface elevation is required to be maintained to near the original river bed elevation (this is the optimal location of the low-level outlets), and flow is required to equal or exceed 95 % of the mean unregulated daily inflow. Drawdown is initiated when the inflow reaches the average unregulated daily value. This approach avoids drawing down a reservoir before inflows are high enough to satisfy flushing discharge requirements, which could result in substantial and uncertain hydropower losses. The quantity of sediment removed during a particular flushing event is determined in each time step using the Long Term Capacity Ratio (LTCR) (Atkinson 1996), which estimates the fraction of a reservoir's initial storage capacity that can be maintained in perpetuity by implementing flushing.

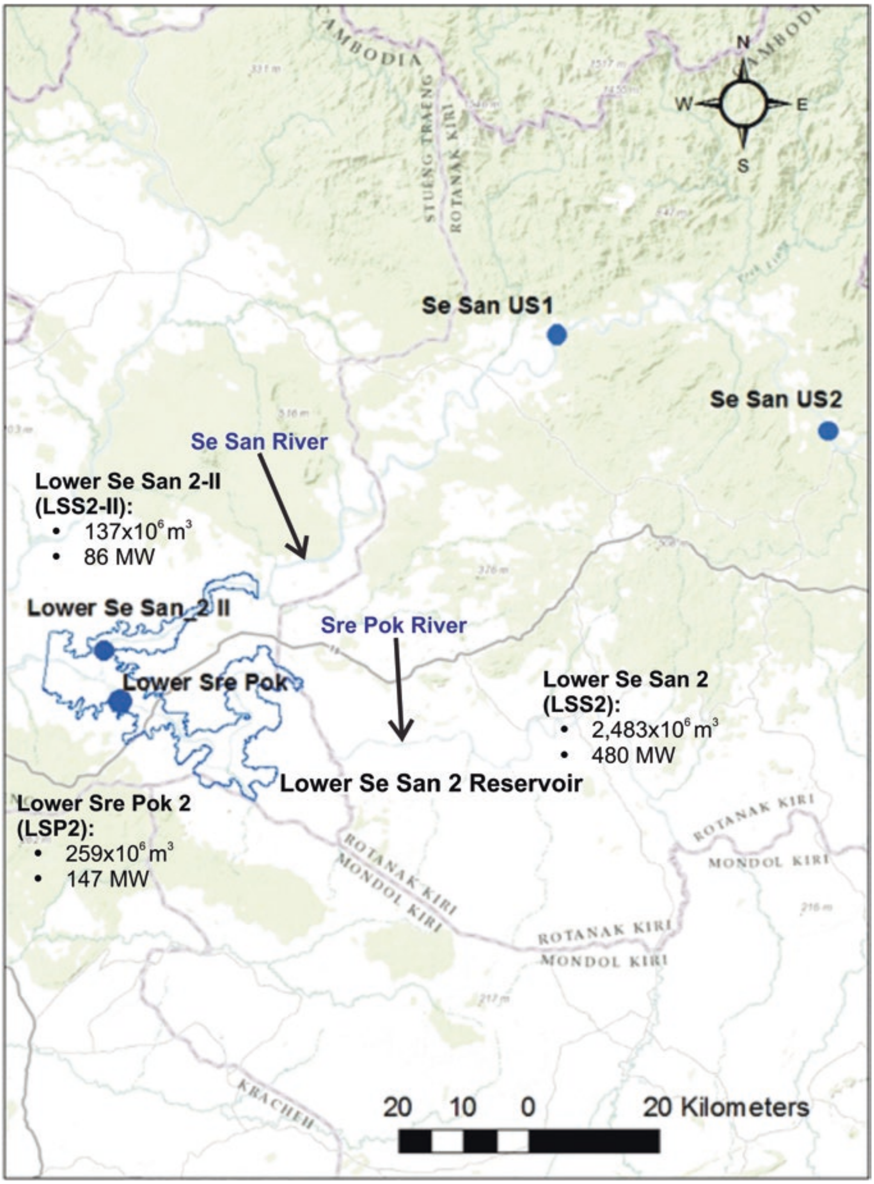

Fig. 2.2 Diagram of the currently proposed Lower Se San 2 (LSS2) Dam, which is proposed to be constructed at the confluence of the Se San and Sre Pok Rivers, and two smaller alternative dams that this study proposes should be considered: Lower Se San 2-II (LSS2-II) and Lower Sre Pok 2 (LSP2). LSS2-II and LSP2, marked by *blue circles*, are proposed within the bounds of LSS2 reservoir as currently planned. Reservoirs Se San US1 and Se San US2, also marked by *blue circles*, are two additional alternative reservoirs that could be sited upstream on the Se San River to make up for the losses in energy generation that would be associated with not building LSS2 as planned. Proposed reservoir storage capacity (m^3) and power plant installed capacity (Megawatts *MW*) are provided for LSS2, LSS2-II and LSP2. Figure adapted from Annandale (2012a)

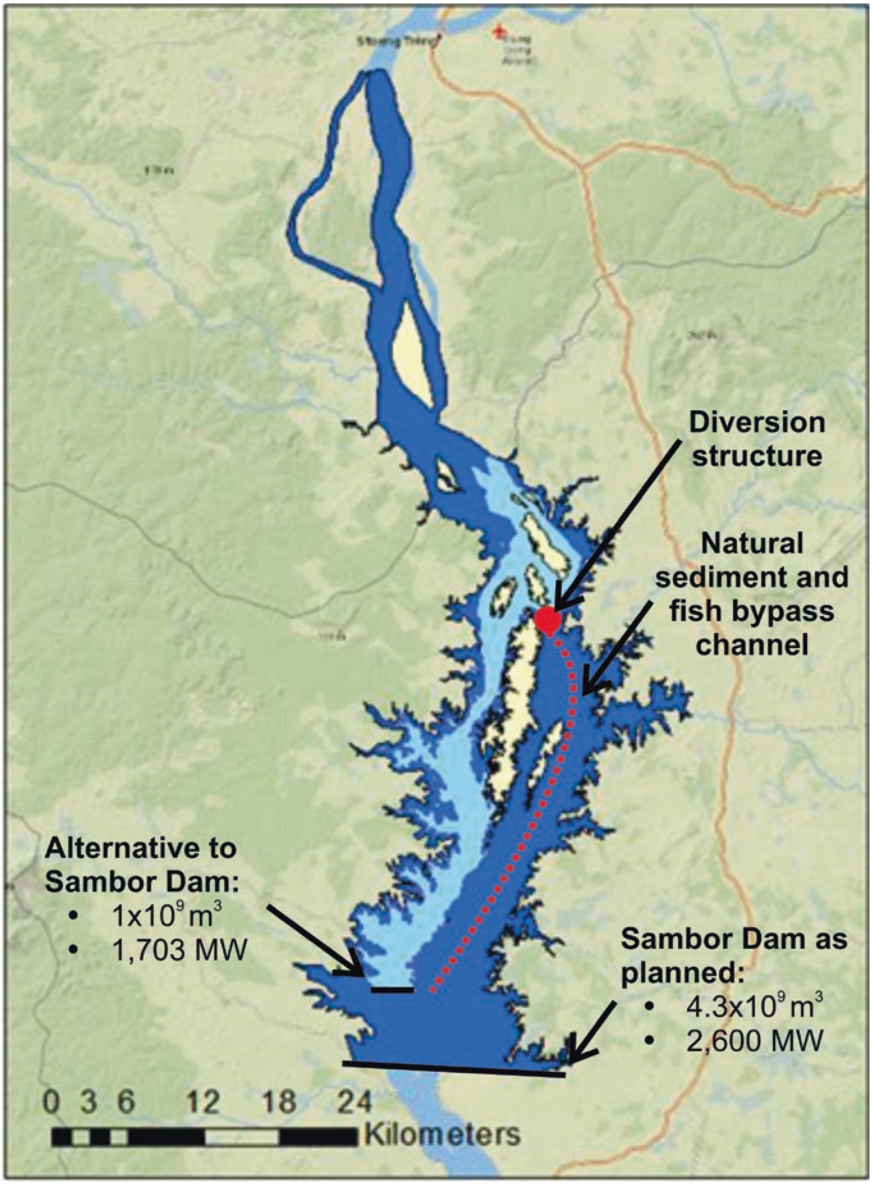

Fig. 2.3 Diagram of the currently proposed Sambor Dam and smaller alternative dam on the Mekong River. The alternative reservoir, appearing in *lighter blue*, would be sited within the bounds of the currently planned reservoir, which appears in a *darker blue*. The *red dashed line* indicates the location of the natural sediment and fish bypassing channels on the East of the alternative site, and the *red dot* indicates the location of a diversion structure that would direct flow and sediment into the diversion channel. Proposed reservoir storage capacity (m^3) and power plant installed capacity (Megawatts *MW*) are provided for the proposed and alternative Sambor Dam. Figure adapted from Annandale (2012b)

To define the range of possible tradeoffs between sediment and hydropower for the possible alternatives, five LSS2 scenarios were considered and six Sambor scenarios were considered. Aside from the unregulated basin scenario, simulations of LSS2 assume the future condition in which the Sre Pok River and Se San River are developed to the maximum extent that is currently planned (19 dams upstream of the LSS2 site, as seen in Fig. 2.1). While 14.3 Mt/yr of sediment is generated upstream of LSS2, only 7 Mt/yr reaches LSS2 in this scenario due to upstream trapping. Simulations of Sambor Dam and alternatives assume the basin upstream of Sambor is developed to the extent of the MRC definite future development scenario (MRC 2011b), or 47 existing and planned dams. While 156 Mt/yr of sediment is generated upstream of Sambor, only 80 Mt/yr reaches Sambor due to upstream trapping (Kondolf et al. 2014).

The five LSS2 scenarios were as follows:

1. Unregulated 3S basins (no reservoirs).
2. Currently proposed Lower Se San 2 (LSS2).
3. Alternatives Lower Se San 2-II (LSS2-II) and Lower Sre Pok 2 (LSP2). No flushing.
4. Alternatives LSS2-II and LSP2. Annual flushing.
5. Alternatives LSS2-II and LSP2. Biannual flushing (every 2 years), both reservoirs being flushed during the same year.

The six scenarios considered for the Sambor alternatives are listed below. Compared to LSS2, flushing frequency is not varied for the Sambor alternative because the results of varying flushing frequency at Sambor are similar to the results shown for LSS2-II and LSP2.

1. Unregulated Mekong Basin (no reservoirs constructed upstream of Sambor).
2. Currently proposed Sambor Dam without sediment management.
3. Alternative Sambor Dam without sediment management.
4. Alternative Sambor Dam with annual flushing.
5. Alternative Sambor Dam with a sediment bypass channel.
6. Alternative Sambor Dam with a sediment bypass channel and annual flushing.

2.4 Results and Discussion

Presenting a comprehensive assessment of the tradeoffs between sediment passage and hydropower production is difficult because the tradeoffs occur over different time scales. For example, the results here will focus on tradeoffs between annual and mean monthly sediment loads and energy production, whereas in reality many other time scales and measures are just as important for sediment, energy and indirectly, biodiversity.

Beginning with LSS2 at the annual time scale, Fig. 2.4 demonstrates the potential impact of LSS2 Dam as currently planned, as well as the potential

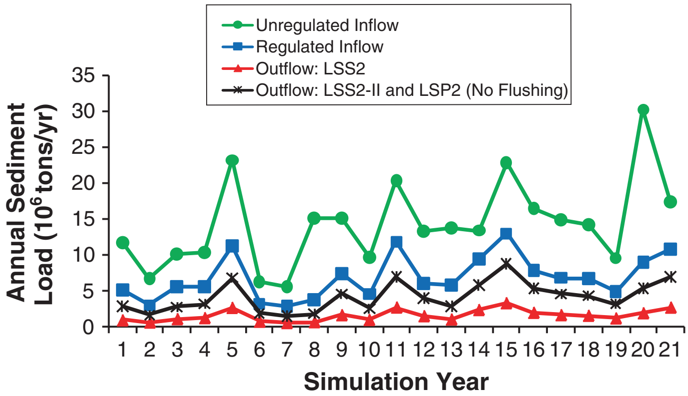

Fig. 2.4 Simulated annual sediment load (10^6 t) inflows and outflows for 21 years for the currently proposed Lower Se San 2 (LSS2) Dam site, and for two alternative dams, Lower Se San 2-II (LSS2-II) and Lower Sre Pok 2 (LSP2), excluding flushing practices. The outflow time series corresponding to LSS2-II and LSP2 are combined into one time series. (Wild and Loucks 2013, with permission from ASCE)

improvement in sediment passage that could be achieved by implementing sediment management practices. Aside from the regulated and unregulated sediment inflow to the LSS2 site, Fig. 2.4 includes cases in which (1) LSS2 is built as planned, and (2) LSS2 is divided into two smaller reservoirs (LSS2-II and LSP2), without any form of sediment management implemented. The purpose of Fig. 2.4 is to highlight what potential impact any form of sediment management (e.g., flushing) could have if implemented.

Figure 2.4 illustrates several important points. First, the unregulated sediment load at the LSS2 site will be significantly reduced due to trapping by the 19 reservoirs expected to be constructed upstream. The simulated effect of the upstream reservoirs is to reduce the mean annual sediment inflow to the site by 51 % (from 14.3 Mt/yr to about 7 Mt/yr). The proposed LSS2 reservoir would then trap 77 % of the remaining load on average, reducing the annual discharged load from 7 to 1.6 Mt/yr. While the significant difference between unregulated inflow and sediment outflow for each management scenario is largely driven by the trapping of sediment in the 19 reservoirs upstream, in the absence of extensive upstream reservoir development, LSS2 would still have the potential alone to trap much of the sediment expected to be trapped in reservoirs upstream, given its high average trapping efficiency of 77 %.

To increase the discharged load from 1.6 Mt/yr to a value that more closely resembles the inflow, LSS2 could be replaced with two smaller reservoirs: LSS2-II and LSP2. The combined effect of the smaller two dams would be to reduce the average trapping efficiency from 77 % (LSS2) to 40 %, which would reduce the trapped load from 7 to 4.1 Mt/yr. This is more than a 150 % increase in annual sediment load discharge compared to LSS2. This improvement is attributed only to reservoir resizing and relocation, which naturally reduces sediment trapping without implementing any sediment management techniques. Appropriate sediment management practices have the potential to produce additional increases in sediment discharge (i.e., to produce an annual sediment load time series that lies somewhere between the middle two time series in Fig. 2.4).

If LSS2 is constructed as planned, approximately 18 % of its 2.5 billion m^3 storage capacity would be lost to sedimentation after 100 years, assuming an average bulk density of 1,200 kg/m^3 for deposited sediment (Xue et al. 2010). Thus, the potential ecological benefit of increasing sediment discharge through the LSS2 site is more likely to serve as motivation for conducting sediment management than a desire to mitigate impacts on long-term energy production. However, if the Sre Pok and Se San basins are ultimately developed to a lesser extent than expected (i.e., if fewer than 19 dams upstream of LSS2 are ultimately constructed), sedimentation at LSS2 could increase significantly, thereby increasing the likelihood of long-term energy production impacts if sediment is not managed.

Having described the potential for sediment management to improve sediment flows downstream of the LSS2 site, Fig. 2.5 demonstrates the impact that specific management techniques could have on the sediment regime downstream. This figure focuses on mean monthly sediment loads, instead of annual sediment loads, because the monthly time scale reveals that sediment management methods such as flushing can alter the seasonal distribution of sediment loads. This in turn may have important ecological consequences.

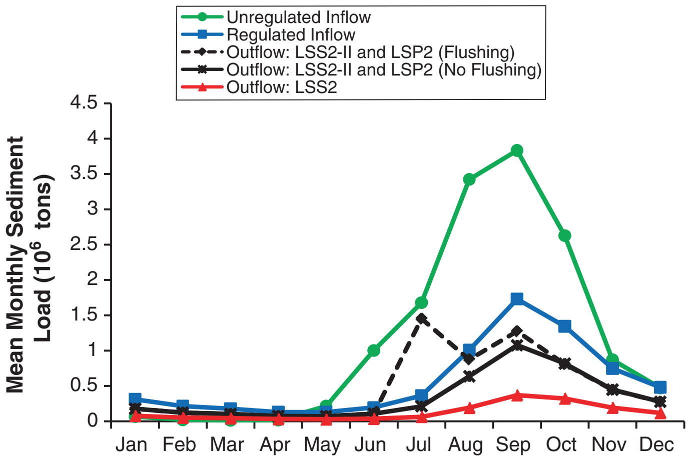

Fig. 2.5 Mean monthly sediment load (10^6 t) inflows and outflows at Lower Se San 2 (LSS2) Dam site. All outflow time series result from the regulated inflow time series. This demonstrates the simulated potential for alternative reservoirs Lower Se San 2-II (LSS2-II) and Lower Sre Pok 2 (LSP2), combined with flushing, to improve sediment passage compared to current plans for LSS2. The outflow time series corresponding to LSS2-II and LSP2 are combined into one time series for comparison to LSS2. Annual and biannual flushing produce similar mean monthly sediment outflows, so they are represented by the same time series

Figure 2.5 demonstrates that the currently proposed LSS2 Dam will significantly reduce the regulated sediment load inflow at the LSS2 site, despite the significant trapping that will already take place in upstream reservoirs. (The uppermost time series in Fig. 2.5, which represents the unregulated inflow into the site, does not serve as sediment inflow in the simulations used to create the sediment outflows in Fig. 2.5. Rather, the regulated time series represents the inflow pattern used to produce the simulation results.) The combined mean monthly sediment outflow from the smaller two reservoirs (LSS2-II and LSP2), without any sediment management implemented, is a clear seasonal improvement to the proposed LSS2. Figure 2.5 demonstrates that annual and biannual flushing could further increase sediment passage at the alternative sites.

Flushing significantly increases sediment load discharge compared to the currently proposed LSS2 and to the alternatives LSS2-II and LSP2 without any sediment management implemented. However, the extent to which this increased sediment discharge represents an improvement depends on the time scale of interest. In general, annual sediment loads, which are not shown here, are significantly increased as a result of the alternative configurations and sediment management practices. This represents a major improvement to the integrity of the geomorphologic system. For example, annually flushing LSS2-II and LSP2 results in a reduction in mean annual sediment load of only 16 % compared to the regulated inflow (i.e., 5.8 Mt/yr discharge is produce from 7 Mt/yr inflow), meaning that only 16 % of the inflowing sediment load is trapped in the two alternative reservoirs. The case in which flushing is performed biannually results in similar average trapping (18 %). Importantly, while less frequent flushing has the potential to produce similar long-term mean annual sediment loads to more frequent flushing, the variance in loading associated with less frequent flushing is far less environmentally friendly, producing larger sediment loads when flushing events occur, and at intervals less frequent than the natural annual intervals to which the aquatic ecosystem has likely adapted.

Transitioning now to the monthly time scale, flushing alters the timing and distribution of mean monthly sediment loads. This is primarily because sediment flushing is performed for a short duration of time during periods of relatively lower flows. Thus, all flushing scenarios result in a mean peak sediment load occurring on average 2 months before the natural mean peak. On average, these values are 300–400 % higher than the mean regulated sediment inflows. However, the flushing spike in mean sediment discharge at the end of the wet season is still enclosed within the bounds of the unregulated mean monthly sediment load inflows. This is an important result because one of the goals of sediment management in this region should be to maintain some consistency with the natural seasonal sediment load regime.

The visible spike in sediment load released from LSS2-II and LSP2 (Fig. 2.5) does not exceed the mean monthly unregulated sediment load inflow, but could still be a significant ecological problem if the loads released produce high enough concentrations for a long enough period of time (Newcombe and MacDonald 1991; Newcombe and Jensen 1996). Additionally, if the downstream channel does not have sufficient capacity to transport the flushed sediment loads downstream of the reservoir, large quantities of sediment may settle in the channel, which can kill larvae and juveniles, and destroy spawning grounds (Hess and Newcomb 1982; Buermann et al. 1995; Brandt and Swenning 1999). These issues require further investigation in the Mekong Basin, as specific impacts will depend on the sensitivity of particular plant and animal species to spikes in concentration and changes in riverine habitats. Previous studies have not assessed such possible flushing impacts on the large diversity of fish species living in the Mekong basin. Ultimately, the environmental impact of flushing will depend on how flushing is implemented in practice. For example, after flushing is completed, clear water should be released from mid-level outlets to wash away flushed sediment that may accumulate in the downstream channel (Fruchart 2008).

It is also useful to assess the wet season implications of conducting sediment management, as the annual flood pulse drives the Mekong basin's productivity through the transport of most of the annual flow, sediment and nutrients. Referring to the results of implementing flushing displayed in Fig. 2.5, after the two mean monthly sediment peaks in July and August, a second, lower peak then occurs in September. This peak would have occurred in the absence of sediment management (note the similarity in September to the case in which no sediment management is attempted). The 19 reservoirs to be constructed upstream of the LSS2 site would reduce the mean sediment load in the three wettest months (August, September and October) by 58 % (9.9–4.2 Mt). The currently proposed LSS2 would further reduce the sediment load in the wettest 3 months by about 79 % (from 4.2 Mt to 0.9 Mt). LSS2-II and LSP2 without flushing reduce wet season sediment outflows by only 40 % (4.2–2.5 Mt). Reduction in the mean sediment inflow (4.2 Mt) in the 3 month peak wet period is only about 28 % when flushing is conducted.

Sediment management measures clearly have the potential to increase sediment discharge downstream of dams in the Mekong basin. However, the sediment management measures proposed here have significant implications for hydropower production. Conducting sediment management has two primary impacts on the sediment regime, and two primary impacts on energy production. Reducing the volume of water storage at the LSS2 site by constructing the two smaller reservoirs, as well as flushing the two smaller reservoirs, creates two sediment impacts: less sediment is trapped, and sediment that is trapped can be removed via flushing. With regard to hydropower, reducing reservoir size, and conducting flushing at those smaller reservoirs, have two primary impacts: smaller reservoirs produce less energy due to reduced operating head and installed capacity, and flushing reduces energy production as generators are taken offline when the reservoir is emptied to conduct flushing. Figure 2.6 highlights these two hydropower impacts by plotting monthly mean energy production for the same scenarios for which the sediment implications are displayed in Fig. 2.5. Due to their reduced combined installed capacity (233 MW), LSS2-II and LSP2 are not capable of combining to entirely replace the energy production of the proposed LSS2 (480 MW). The reduced combined generating capacity is responsible for the majority of the 58 %

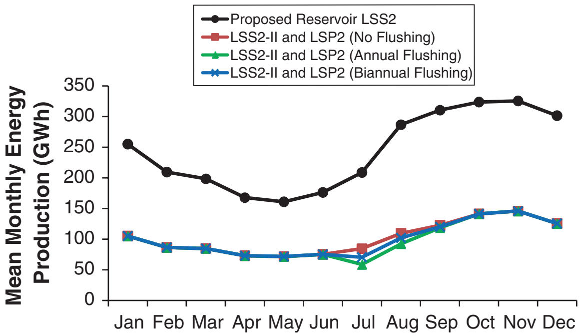

Fig. 2.6 Simulated mean monthly hydropower energy production in Gigawatt hours (GWh) associated with the currently proposed Lower Se San 2 (LSS2) Dam and two alternative dams, Lower Se San 2-II (LSS2-II) and Lower Sre Pok 2 (LSP2), with flushing implemented (Wild and Loucks 2013, with permission from ASCE)

reduction in mean annual energy (2,925–1,225 GWh) that would result from building LSS2-II and LSP2 instead of LSS2.

There is also a loss in power production associated with flushing. Annually flushing LSS2-II and LSP2 reduces mean annual energy production (compared to not managing sediment in these reservoirs) by only about 4 %, whereas biannual flushing results in mean annual reductions of only 2 %. Flushing avoids significant losses in annual power generation because the process can be conducted relatively quickly. Thus, flushing alone does not critically impact average annual or monthly power production. This is a significant result because one or two more dams could be constructed upstream of LSS2-II and LSP2 (e.g., Se San US1 and Se San US 2 in Fig. 2.2) to continue to replace the installed energy generating capacity that is lost by not constructing LSS2 as planned. While potentially more costly to construct several dams instead of one, such a system of dams could replace much of the energy generating capacity of LSS2, with potentially relatively insignificant energy losses from the flushing process and increased sediment outflows. The latter statement, however, ignores two critical issues that will be addressed next.

First, while flushing is taking place, no power is being produced because generators are taken offline. This will impact the reliability of power production. Performing flushing at LSS2-II and LSP2, compared to when no sediment management is performed, results in a loss in reliability for every level of power production, especially firm power. Reliability impacts will be assessed in the future as more information becomes available about the role these reservoirs play in the energy grid. Second, Fig. 2.6 focuses on short-term energy production, whereas the positive impacts of sediment management become more visible in the long term, as sediment accumulation progressively impacts operations at dams where sediment (and therefore the reservoir's storage capacity) is not sustainably managed.

The sediment management alternatives for Sambor Dam offer a similar set of tradeoffs between sediment passage and hydropower production. That is, the alternative Sambor Dam is smaller, which improves sediment passage and makes flushing feasible. However, the smaller installed capacity and flushing process reduce energy production. The reduced reservoir storage means the alternative Sambor reservoir has an average trapping efficiency of 32 % compared to the currently proposed Sambor (50 %). This reduction translates into a large increase in sediment load passage, given the location of Sambor at the lower end of the river basin. In an unregulated system (about 160 Mt/yr inflow), this 18 % reduction in trapping efficiency would result in a sediment discharge increase of about 29 Mt/yr, whereas in the system regulated to the extent of the MRC definite future scenario (80 Mt/yr inflow), the increase is about 14.5 Mt/yr. As with the LSS2 alternative discussed previously, the Sambor alternative has the additional advantage that sediment flushing is feasible. The associated increases in sediment passage depend on the frequency with which flushing is conducted. Additionally, the different location of the Sambor alternative compared to the currently proposed location creates the possibility of a natural sediment bypass. The potential impacts of both flushing and the sediment bypass are demonstrated in Fig. 2.7. This figure shows the mean monthly sediment loads flowing into and discharged from the proposed and alternative Sambor Dam configurations.

If Sambor Dam is constructed as planned, much of its storage capacity could be lost due to sedimentation during the operating lifetime of the dam. The approximately 50 % trapping efficiency of the planned dam suggests an annual sedimentation of 40 Mt, which is more than 33 million m^3 of sediment per year assuming an average bulk density of 1,200 kg/m^3 for deposited sediment (Xue et al. 2010). In 50 years, almost 40 % of the initial storage capacity could be lost to sedimentation. The storage capacity lost after 100 years will depend on how trapping efficiency declines at the site over time due to reduced storage capacity, but certainly more than 50 % loss in initial storage capacity appears possible. Such a significant loss in storage capacity could potentially impact energy production and other

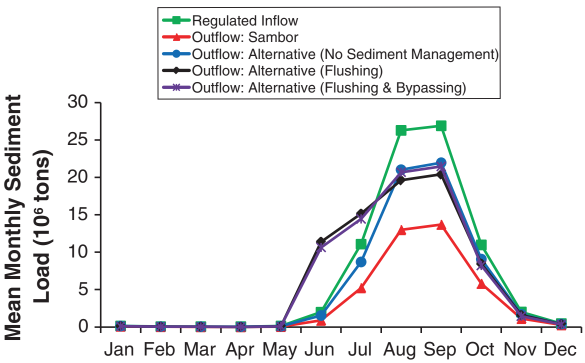

Fig. 2.7 Mean monthly sediment load (10^6 t) inflows and outflows at Sambor Dam site. All outflow time series result from the regulated inflow time series. This demonstrates the simulated potential for the Sambor alternative reservoir proposed here, combined with flushing and sediment bypassing, to improve sediment passage compared to current plans. The case in which bypassing is conducted without flushing is not shown, as sediment outflows were not significantly different from the outflows corresponding to no sediment management

dam functions, though the specific impacts will depend on the reservoir's operating policy, which is not known at this time. (Note that these assessments assume a consistent 80 Mt/yr mean annual influx of sediment. Declining sediment inflows due to construction of reservoirs throughout the LMB upstream could reduce sedimentation impacts at Sambor.) Clearly, constructing a smaller reservoir with flushing and bypassing capabilities may be ecologically and operationally beneficial.

Simulation results indicate that implementing annual or biannual flushing at the site would increase sediment discharge by about 19 % compared to the case in which no sediment management is implemented at the same alternative dam (77.3 Mt/yr instead of 64.7 Mt/yr). As was the case with LSS2 flushing alternatives, the increased sediment discharge during flushing is produced on average early in the wet season (or late in the dry season). Once again this may have important ecological implications.

Surprisingly, conducting sediment bypassing does not produce any increase in mean monthly sediment discharge compared to the case in which no sediment management is implemented at the same alternative dam. This does not mean that the sediment bypass does not work. In fact, the sediment bypass effectively diverts about 28 % of the inflowing sediment around the reservoir, resulting in reduced sediment inflows to the reservoir. However, the sediment bypass diverts large quantities of water around the reservoir during the flood season. This in turn increases the residence time of water and sediment in the reservoir during this period, thereby increasing the trapping efficiency from what it would otherwise be. Thus, the benefit of diverting 21.8 Mt/yr of sediment around the reservoir is offset by the increased trapping efficiency for the 72 % of sediment that is not bypassed.

The relative improvement in sediment discharge that is possible with the sediment bypass depends on the trapping efficiency of the reservoir. For example, results from other simulations (not discussed here) demonstrate that if the trapping efficiency of the reservoir without sediment management is 45 % instead of 32 %, the bypass would instead produce an increase in sediment load discharge of 22 % compared to the reservoir without sediment management implemented. When both flushing and bypassing are implemented at the same time, there is only a very slight improvement in sediment discharge (0.25 Mt/yr) compared to the case in which the reservoir is only flushed (and no bypass exists).

To further explore this result regarding the bypass, future work should include sensitivity analysis that explicitly accounts for the impact of the following factors on the relative effectiveness of the sediment bypass: (1) the fraction of the suspended sediment load that is distributed into the bypassed flow versus into the reservoir; and (2) trapping efficiency, which affects the incremental sediment benefit bypassing offers when both flushing and bypassing are conducted. Regarding the former factor, if the bypass diversion structure is constructed such that much of the suspended load in the water column can be distributed into the bypassed flow, the bypass could be much more effective than is reported here. Regardless of its potential influence on the sediment balance at Sambor, the sediment bypass option is important to consider because it offers a natural fish passage system; would inundate less surface area; and would likely be much more effective than flushing at preventing accumulation of bedload in the reservoir.

Just as with LSS2, the Sambor Dam alternative produces two primary impacts to power production: a loss in energy production due to reduced installed capacity, and a loss in energy production associated with the requirement that generators be taken offline during flushing. The results are not shown here because they are similar in appearance to the LSS2 energy impacts shown in Fig. 2.6. The reduced size of the Sambor Dam alternative results in about a 35 % loss in annual energy production, mostly due to reduced installed capacity. Conversely, annual flushing further reduces annual energy production by only about 2 %. Regarding the bypass, aside from the potential sediment and fish passage benefits, an additional advantage is that hydropower production can proceed normally during the bypassing process every year. This is because the installed turbine flow capacity at the currently proposed dam (and the Sambor alternative discussed here) is only twice the mean annual inflow rate (27,600 m^3/s). During the monsoon season the sediment bypass only diverts the portion of reservoir inflow that exceeds twice the mean annual inflow rate, so water that is diverted during bypassing would not have produced hydropower anyway.

2.5 Uncertainty Issues

The results presented in this paper rely on a variety of assumptions regarding the values of uncertain model parameters, for both the proposed dams (LSS2 and Sambor) and the multitude of dams that are proposed to be constructed upstream of them. The largest sources of uncertainty in the results presented here are related to inaccurate estimates of (1) sediment production and (2) sediment trapping efficiency. Regarding sediment production, the quantity of sediment produced in the Mekong basin is currently uncertain. Particularly in the 3S basins and on the mainstream Mekong River near Sambor, more frequent and spatially distributed sediment sampling, including grain size distributions and bedload estimates, are necessary to prepare more certain estimates of sediment production. Grain size distribution data will also enable improved estimates of reservoir sediment trapping efficiency, as will sedimentation records from existing reservoir sites. Both can be used to calibrate modeling assumptions regarding trapping efficiency.

Ultimately, both the quantity of sediment produced and the trapping efficiency of that sediment load (not just at LSS2 and Sambor, but at upstream reservoirs) will determine the quantity of sediment that is trapped. This controls (1) the potential impact that neglecting to conduct sediment management has on storage capacity and long-term energy production, and (2) the magnitude of sediment that could be released when flushing is conducted. Additional data, such as reservoir operating policies and improved total storage estimates, will enable improved predictions of sediment trapping and an improved understanding of the roles particular reservoirs (e.g., LSS2 and Sambor) play in the energy grids they serve. In the absence of the data outlined above, future work should include sensitivity analysis that explicitly varies assumptions regarding sediment production, sediment trapping efficiency (based on sediment size), and reservoir operating policies to capture the range of potential tradeoffs between sediment regime restoration and energy production.

2.6 Conclusions

Water resources infrastructure in the Mekong River Basin is growing at a rapid pace. This infrastructure will impact the natural flow and sediment regimes that in turn can impact the natural ecosystem of this biodiverse river and its basin. Sediment management opportunities should be considered for two reasons. First, it is important that lessons about successful implementation of sediment management practices be learned soon, so they can be applied throughout the basin to achieve sediment goals for the entire system. Second, retrofitting existing dams with sediment management facilities (e.g., low- and mid-level outlets) can be costly, so it is critical that dams be designed and constructed with sediment management goals in mind.

Our simulations suggest that as currently proposed, LSS2 Dam and Sambor Dam would trap large quantities of sediment, starving downstream ecosystems of this resource that transports nutrients and maintains the geomorphic makeup of the system, among other functions. Results of simulations also suggest that sediment management practices have the potential to reduce these adverse impacts. Reservoir re-location and resizing, along with frequent implementation of sediment flushing, could significantly increase sediment discharge compared to the current plans for LSS2 and Sambor. An additional opportunity at Sambor is a sediment bypass, the potential effectiveness of which appears promising but must be further evaluated. In addition to improved sediment passage (particularly for bedload), the Sambor alternative provides a natural fish passage channel. This could mitigate the potentially severe consequences (for the Mekong fishery) of building a dam on the Mekong River that would block major fish migration routes in the vicinity of critical ecosystems (Tonle Sap Lake and the Vietnam Delta).

While the management techniques evaluated here enable increased sediment passage, this benefit comes at a cost: diminished short-term energy production. Energy production is reduced for reservoirs at which sediment management is practiced, due to (1) the reduced reservoir size required to conduct sediment management, and (2) the flushing process itself that requires generators be taken offline. The majority of hydropower energy is lost because the smaller alternative reservoirs have smaller installed plant capacities, rather than due to the implementation of the sediment management practices (e.g., flushing and bypassing). This creates the possibility that numerous smaller dams could be constructed to replace the energy lost from one larger dam, particularly in the case of LSS2. The cost and long-term energy implications of this approach, as well as the potential increased difficulty of managing sediment in multiple dams, should be explored in future work. These lessons about tradeoffs are not limited to LSS2 and Sambor; rather, the findings discussed here have important implications for dams throughout the Mekong Basin, given the similarity in the monsoon-driven inflow and sediment conditions for various planned dams. Of course, the cost of sediment management with regard to hydropower losses will vary among sites, depending upon the objectives of different reservoirs, including the roles they serve in the energy grid.

Several issues highlighted in this paper should be investigated in future work. To begin, sensitivity analysis is required to better understand the effect of a variety of modeling assumptions on the results shown here. The effectiveness of different sediment management approaches, such as sediment bypassing, change depending upon various assumptions. The relative importance of these assumptions should be identified so data collection efforts can be prioritized. Next, the timing and magnitude of sediment released during flushing in the simulations described here are potentially inconsistent with the system's natural sediment regime, and could thus be harmful to the basin's ecosystems. Discussion in this paper has revolved around mean monthly and annual sediment loading released during flushing, whereas maximum daily sediment concentrations during flushing, and the duration of those concentrations, may be more important metrics for assessing potential impacts to the health of aquatic species and their habitats. These potential effects can be quantified with more detailed modeling and observation to assess the true potential of the techniques discussed here. Finally, assessment of the potential benefits of sediment management must account for the long-term benefits that are possible by maintaining a sustainable storage capacity. This study focused on short-term losses in hydropower production associated with sediment management, whereas the true benefit of flushing is more visible in the long term, when sedimentation will result in diminished functionality at reservoirs where sediment is not managed.

Acknowledgments This work is being performed in conjunction with the Natural Heritage Institute (NHI), and is funded by a grant from the U.S. Agency for International Development (USAID), Cooperative Agreement No. AID-486-A-11-00002. The authors wish to thank the Mekong River Commission for providing data and advice throughout our studies, including reservoir and dam characteristics data and streamflow data. We extent our gratitude to Matt Kondolf and Zan Rubin for helpful discussions and sediment load predictions; to Tom Cochrane, Thanapon Piman and Mauricio Arias for help generating 3S basins maps (Fig. 2.1) and simulating 3S basins flows; and to George Annandale for helping to improve the *SedSim* model, and for developing the sediment management alternatives we evaluated in this study. We also thank the reviewers of previous drafts for their helpful comments that improved this manuscript.

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Chapter 3
Groundwater Management Instruments and Induced Second-Order Conflicts: The Case of the Paraíba River Basin, Brazil

Zédna M.C.L. Vieira and Márcia M.R. Ribeiro

Abstract Management measures addressing water scarcity are often pointed out as resolution alternatives for first-order conflicts; however, failures in introducing such measures or their unforeseen consequences can transform them into sources for second-order conflicts caused by social resource scarcity. Hence, implications of their adoption should be analyzed. Considering unsustainable groundwater use in the Paraíba River Basin—the most important basin in the state of Paraíba, Northeastern Brazil—and focusing on water quality guidelines, water permits, and bulk water charges, this paper analyzes thirteen criteria for applying these management instruments with regard to their potential for inducing second-order conflicts, and identifies the possible consequences of their adoption. Then, utilizing the Graph Model for Conflict Resolution (GMCR), these consequences are introduced as management outcomes to model the conflict over groundwater residential supply in João Pessoa, the state's capital. The analysis/modeling results can support decision-making on options to avoid/minimize second-order conflicts over groundwater management.

Keywords Management criteria · Graph model for conflict resolution (GMCR) · Water permits · Bulk water charges

3.1 Introduction

In Brazil, the National Water Policy (Federal Water Law 9433/1997) establishes water management that is *integrated*, considering all the phases of the hydrological cycle, *decentralized*, where the river basin is the territory unit for water planning and management, and *participatory*, in which decision-making involves water

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_3

users, civil society, and the governmental sector. The policy should be implemented through the application of five management instruments, namely: (1) *water plans*, which are developed to guide future decisions, establishing priorities and general mechanisms for water allocation and water pricing; (2) *water quality guidelines*, which intend to guarantee that water quality is compatible with the target use of each water body; (3) *water permits*, which seek to balance supply and demand sides through water use authorization; (4) *bulk water charges*, which recognize water as an economic good, encouraging responsible and rational water use and for collecting revenues to improve the basin's conditions; and (5) *water information system*, a database on water availability, uses, users, and so on, to support decision-making. These five instruments are complementary and their relationship can be summarized as follows: based on the water information system, the water plan defines the goals in relation to water quality and quantity; therefore, water quality guidelines, water permits, and bulk water charges constitute "operative instruments", since it is their implementation that may induce the necessary changes in water use patterns for achieving the water plan goals. Besides, bulk water charges can only be applied to the water uses granted by water permits, and water permits must consider the standards established by water quality guidelines; evidently, reliable information is necessary to guarantee the effectiveness of these instruments.

After seventeen years of the Water Law promulgation, although the Brazilian Water Policy has already achieved several effective advances, there is a clear emphasis on surface water management. As a result, the management instruments fail to consider groundwater specificities, and that hinders integrated management from being accomplished (Ribeiro et al. 2012). This gap in relation to groundwater management allows unsustainable groundwater use patterns, causing problems like aquifer depletion, salt water intrusion, and groundwater contamination/pollution, among others. Thus, the increasing competition for groundwater resources creates the so-called "first-order conflicts", which are related to demand-induced water scarcity, in the absence/inadequacy of norms and regulations (Ohlsson 1999). Such conflicts call for the application of adequate management instruments.

However, since the application of management instruments demands a societal adaptation effort, "second-order conflicts", which are connected to scarcity of social resources, may be induced by the very means societies employ to overcome the first-order scarcity (Ohlson 1999). Hence, second-order conflicts are likely to occur from the inadequate or unmonitored implementation of water demand mechanisms that seek to achieve a more equitable water distribution (e.g., water permits) or even spring from the use of economic tools which may infringe on traditional values or privileges of previous users (e.g., bulk water charges). In this context, the current gap in relation to groundwater management implies not only in the need to address the adequacy of water management instruments to groundwater specificities, but also the evaluation of such instruments from the point of view of their potential for inducing second-order conflicts.

Thus, this paper adopts as study area the coastal region of the Paraíba River basin, the most important basin in the state of Paraíba, Northeastern Brazil, and where conflicts over groundwater use have been observed. Thirteen criteria for applying water quality guidelines, water permits, and bulk water charges to groundwater management are analyzed. The objectives of this paper are to identify the consequences of the adoption of these criteria, classify their potential for inducing second-order conflicts, and suggest mitigating measures to avoid/minimize such conflicts.

3.2 Conceptualizing Second-Order Conflicts

Literature on water conflicts presents two main approaches. The first, based on classic environmental researches (Homer-Dixon 1994; Bächler et al. 1996; Gleditsch 1997), links water conflicts to water scarcity, both the scarcity caused by the heterogeneous spatial-temporal distribution of water (arid and semi-arid climates, periodic droughts) and the scarcity motivated by human activity impact on water resources (desertification, increasing demands, inadequate use patterns, pollution). The second, followed by authors like Glachant (1999), Rogers and Hall (2003), Ravnborg (2004), among others, considers that, more than to water scarcity, water conflicts are related to water governance, that is, the set of political, social, economic and administrative systems for developing and managing water resources at different societal levels (GWP 2002).

Ohlsson (1999) synthesizes these two different approaches. Although still considering water scarcity as the basic source for water conflicts, this author links it to water governance by introducing an important conceptual distinction between first- and second-order scarcities. The former results from hydrological conditions and/or the increasing pressures on available water and can be: (1) induced by demand, due to population growth and its justified demands and/or inadequate use patterns; (2) induced by supply, as a result of quantitative and/or qualitative unavailability of water to meet existing demands; and (3) structurally induced, due to water resources appropriation by powerful social segments. The latter indicates a societal incapacity in finding adequate social tools to deal with the social consequences of a first-order scarcity. Consequently, he distinguishes between "first-order conflicts", which are originated from the competition for scarce water resources (first-order scarcity) in the absence/inadequacy of norms and regulations for managing that scarcity, and "second-order conflicts", which are related to scarcity of social resources (second-order scarcity) and caused by failures in introducing the correct kind/sufficient amount of management measures to overcome the first-order scarcity, or by unforeseen consequences of such measures.

Even in the context of a relatively high level of water availability as is, in general, the case of groundwater resources, first-order scarcity/conflict can occur due to inadequate use patterns which may result in interference among wells, aquifer depletion and groundwater pollution. The effectiveness of management measures to discipline water use and solve first-order conflicts depends on the societal ability to mobilize a sufficient amount of social resources, i.e., institutional capability, economic incentives/disincentives, users' acceptability, etc. (Ohlsson and Turton 2000). For example, the implementation of water permits may change the balance of power among different user sectors, by considering multiple uses; the implementation of bulk water charges can reduce the level of economic activity of given user groups; in both cases, mitigating measures are necessary to minimize these negative consequences and avoid the occurrence of second-order conflicts. However, the feasibility of such measures is related to the availability and correct application of social resources.

3.3 The Brazilian Groundwater Management Legal Framework

The Brazilian National Water Resources Council (NWRC) is responsible for regulating the application of Water Policy instruments. Thus, at federal level, and in relation to groundwater management, the NWRC establishes general criteria to implement water permits (Resolution 16/2001), bulk water charges (Resolution 48/2005), and water quality guidelines (Resolution 91/2008), considering surface water and groundwater conjointly.

Brazil is a Federative Republic, and federal regulations act as general norms to be followed by all its members. On the other hand, the country is very large (more than 8.5 million km^2) and its five geographic regions (comprising twenty-six states and the Federal District) present great hydrological, economic and social differences. So, the NWRC Resolutions cannot be specific and the states can choose the aspects they will adopt.

Thus, in the state of Paraíba:

- Water quality guidelines are not explicitly considered as a management instrument, although the State Water Law authorizes the State Water Resources Council to define water quality targets to be achieved by the state water bodies;
- The Decree 19260/1997 establishes that water permits should adopt, as reference for groundwater withdrawal, the well's nominal flow rate test or the aquifer recharge capacity; when this flow rate is less than 2 m^3 h^{-1}, the use is considered insignificant and no water permit is needed. With this approach, however, the state water permit system doesn't take into account aspects such as the risk of interference among wells, or the proximity of potential pollutant sources;
- In relation to bulk water charges, the Decree 33613/2012 defines the values to be collected according to each water use, without distinguishing between surface and groundwater, and establishes annual volumes which are exempt from charges for each state river basin. For the Paraíba River basin these volumes are as follows: water supply and industrial uses: 200,000 m^3 year^{-1}; agriculture and agricultural-industry: 350,000 m^3 year^{-1}. As a result, the state bulk water charges system doesn't consider the differences between wet and dry seasons, or if high quality water is being destined to less noble uses, among other aspects.

3.4 The Study Area

The Paraíba River basin (Fig. 3.1) is the largest and most important basin under the domain of the state of Paraíba, since the main river and its tributaries lie solely within the state's borders. It covers an area close to 20,128 km^2, of which more than 80 % is inserted in Brazil's semi-arid region (AESA 2006), a drought prone area characterized by low average annual rainfall—concentrated into four months of the year and presenting high inter-annual and spatial variability—, high evaporation rates, intermittent rivers, and crystalline based aquifers which offer very low groundwater availability (Vieira and Ribeiro 2010).

As groundwater occurs mainly in the basin's coastal area, this paper focuses on the Paraíba River Lower Course Region and its sedimentary aquifers. The Region (area: 3,925.4 km^2) includes twenty-five municipalities—among which is João Pessoa, the state's capital—and presents a high urbanization rate (85.68 %) and a demographic density close to 293 inhab.km^{-2} (ASUB 2010). Its Gross Domestic Product is predominantly formed by the service (55.6 %) and industrial (39.4 %) sectors, while the agricultural sector's contribution is very low (5.0 %); its Human Development Index is 0.711, indicating medium human development (IBGE—Instituto Brasileiro de Geografia e Estatística 2010).

The Coastal Sedimentary Basin comprises two distinct aquifer subsystems: a free subsystem, in Barreiras formation; and a confined subsystem, the most important, in Beberibe formation. Although groundwater potential by aquifer unit is not yet known, the entire system potential is 628.48 h m^3 year^{-1}. The State Water Plan defines the maximum groundwater availability as 60 % of this potential (AESA 2006), although current withdrawals sum up to 82.7 % of the potential, characterizing overexploitation in the study area, where there are more than 3,660 wells. Recent studies have revealed wells with negative static levels in relation to the sea

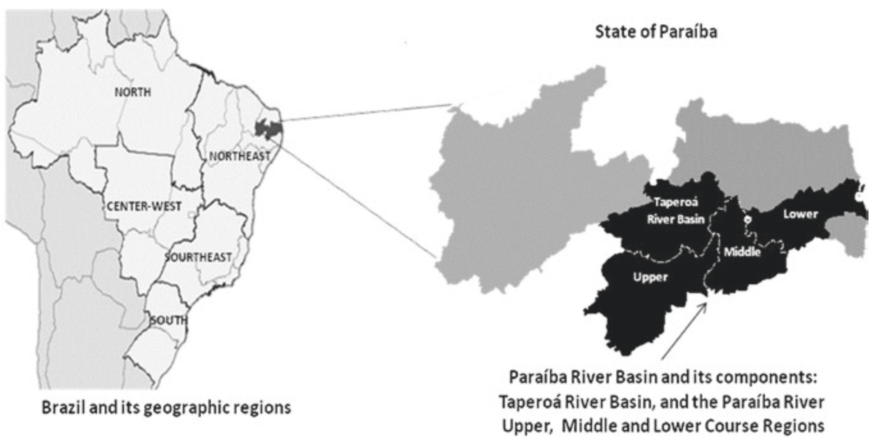

Fig. 3.1 Location and components of the Paraíba River Basin

level, and areas with excessive water table drawdown, especially in the industrial district of João Pessoa city; besides this, salt water intrusion has been detected in some coastal points (ASUB Project 2010).

In João Pessoa city, urban water supply is under the responsibility of CAGEPA (Water Supply Company of the State of Paraíba), the state public water supply company. High tariffs along with eventual failures in meeting demands have made it attractive to drill private wells, notably in residential apartment condominiums along the coastal area. The majority of these wells are clandestine; their water does not always meet quality standards for drinking water; and their concentration, in some areas, has given place to interference among wells and aquifer depletion has already been observed. All these detected problems, which are mainly allowed by the lack of monitoring/punishment actions (already foreseen by the state water legislation), highlight inadequate groundwater use patterns and the absence/inadequacy of groundwater management in the study area, and reveal the occurrence of first-order conflicts.

3.5 Criteria Definition and Analysis

This paper considers the criteria originally suggested by the ASUB Project (2006–2010), which was carried out by the research team on Integrated Water Resources Management of the Federal University of Campina Grande. The main goals of the ASUB Project were: (1) to acquire information (institutional, legal, hydrological, geological, economic, social, groundwater users and use patterns, etc.) about the Coastal Sedimentary Basin of the Paraíba River Lower Course Region; (2) to analyze the water policy's operative instruments (water quality guidelines, water permits, and bulk water charges) with regard to their adequacy to groundwater management; and (3) to indicate management measures/parameters/criteria to guarantee the integration/adequacy of these instruments to groundwater management. In the process of defining criteria for applying groundwater management instruments, three spatial levels were considered (ASUB Project 2010):

- Global, which considers the entire river basin, according to a systemic and integrative view;
- Regional, defined by groundwater recharge and discharge zones, i.e., according to the behavior of physical processes;
- Local, in which the main analysis object is the well and the consequences of its drilling in a given point in the basin.

Table 3.1 presents the thirteen suggested criteria, and indicates their respective spatial level, the management instrument(s) that can use them, the meaning of each criterion and the possible consequences of its application.

As Table 3.1 indicates, all the criteria for applying water quality guidelines and water permits can result in suspension or restriction of granted water permits and/or non-granting of new permits; for bulk water charges, charge values should increase in the context of low groundwater availability, dry season, and high water quality required by the current/intended groundwater use, or diminish in the event of high groundwater

Table 3.1 Criteria and their respective spatial levels, instruments, meanings and consequences

Criterion (Level)	I	Considerations	Possible consequences
1. Priority for using surface water (G)	WP	Groundwater is a strategic resource to be used only if there is no existing surface water supply alternative	Suspension/restriction and/or no new permit
2. Groundwater availability (G)	WP	Total groundwater abstraction should be inferior to 60 % of the potential	Suspension/restriction and/or no new permit
	BW	Differentiates charge values	Increased/decreased values
3. Hydrological seasonality (G)	BW	Differentiates charge values for wet and dry seasons	Increased/decreased values
4. Investments in the basin (G)	BW	User's structural investments in the basin can diminish charges up to 0 %	No investment and no changing in charges values
5.Water use priorities (R)	WQ	Water quality adequacy to each use	Suspension/restriction and/or no new permit
	WP	By law: human and animal supply > industry and commerce > agriculture	
6. Salt water intrusion (R)	WQ	Protection zones implementation in coastal areas can restrict water uses	Suspension/restriction and/or no new permit
	WP	Prevention of salt water advancing	
7. Aquifer vulnerability (R) +	WQ	Protection zones implementation for highly vulnerable aquifers can restrict water uses	Suspension/restriction and/or no new permit
8. Potentially pollutant sources (R)	WP	Prevention of water contamination	
9. Water quality (L) +	WQ	Well's water adequacy for water uses	Suspension/restriction and/or no new permit
10. Kind of use (L)	WP	Verification of current/intended uses	
11. Interference between wells (L)	WP	Based on the well's radius of influence and water table maximum drawdown	Suspension/restriction and/or no new permit
12. Demand man-agement measures (L)	WP	Need for users' actions that reduce waste and guarantee rational water use	Suspension/restriction and/or no new permit
13. Aquifer classification versus kind of use (L)	BW	Differentiates charge values based on the level of (high/low) water quality the use requires	Increased/decreased values

Obs. Level Spatial level [*G* Global, *R* Regional, *L* Local]; *Instr.* Instrument [*WQ* Water Quality Guidelines, *WP* Water Permits, *BW* Bulk Water Charges]; *Considerations* indicate the meaning of each criterion; *Possible Consequences* indicate the consequences from applying the instrument using the criterion availability, wet season, low water quality required by the current/intended groundwater use, and/or authorized and confirmed users' investments in the basin.

3.6 Criteria Potential for Inducing Second-Order Conflicts

The potential presented by each criterion for inducing second-order conflicts was classified into four categories, according to the following conditions:

- Low, if the criterion maintains current groundwater use patterns;
- Medium, if the criterion slightly modifies current groundwater use patterns, implying in the need for few restrictions in existent/new water permits and/or insignificant increases in bulk water charges values;
- High, if the criterion forcefully modifies current groundwater use patterns, implying in the need for many restrictions in existent/new water permits and/or significant increases in bulk water charges values;
- Very High, if the criterion prevents groundwater use, implying in the suspension of existent water permits and the no-granting of new ones, or important increases in bulk water charges values.[1]

Thus, in the light of current groundwater use patterns in the study area, analysis of consequences most likely to occur allowed the determination of the criteria potential for inducing second-order conflicts. Table 3.2 indicates the overall criteria analysis results. As an illustration, the summarized analysis performed for two global criteria and its results are presented below.

- Criterion #1. Priority for using surface water: the Paraíba River is perennial just in its Lower Course Region. Reservoirs located in other river basins are surface water sources for the major cities in the study area; all of these cities are already served by the water supply company, which utilizes both surface water and groundwater sources. In rural areas, on the other hand, there is no public water supply service and, in most cases, the distance between farms and surface water sources is very large. Hence, the costs of replacing groundwater with surface water in urban areas and using surface water instead of groundwater in rural areas would be very high. The application of this criterion to urban areas implies in the need for suspending water permits granted for private groundwater use and the non-granting of new water permits for such use. Considering the numerous private wells (including those clandestine ones) existent in the urban zones in the study area, the potential for inducing second-order conflicts is very high. Current groundwater users would be unlikely to submit to a command-and-control instrument implementation and clandestineness would very likely increase. Thus, the criterion potential for inducing second-order conflicts is Very High.

[1] Increases in bulk water charges values are considered insignificant (<3 %), significant (from 3 % up to 10 %), and important (>10 %), according to the economic conditions in the study area.

Table 3.2 Criteria's potential for inducing second-order conflicts

Criterion	Potential classification (observations)
1. Priority for using surface water	Very high (especially in urban areas)
2. Groundwater availability	High to very high (abstractions surpass 60 % of potentiality)
3. Hydrological seasonality	Low (wet seasons) or very high (dry seasons)
4. Investments in the basin	High (need for the users' own investments)
5. Water use priorities	Medium (a few changes required to attend specific areas)[a]
6. Salt water intrusion	High (in coastal areas and irrigated areas)
7. Aquifer vulnerability +	Low (confined aquifer, especially in rural areas) to
8. Potentially pollutant sources	Very high (free aquifer, especially in urban areas)
9. Water quality +	Low (water quality is adequate for the intended use) to Very
10. Kind of use	High (advanced water treatment is need for allowing the intended water use)
11. Interference between wells	Low to medium (in rural areas) and high to very high (in urban areas, especially in the study area's major cities)
12. Demand management measures	High (in the entire study area)
13. Aquifer classification versus kind of use	Low (low water quality and mean water uses) to very high (high water quality and noble water uses)[b]

[a]According to the municipalities' economic basis, irrigation can be more important than industry
[b]The higher the water quality the higher the charges to be paid

- Criterion #3. Hydrological seasonality: during dry seasons, the adoption of this criterion for applying bulk water charges would increase the total amount to be paid by users, with the desired effect of inducing groundwater rational use. On the other hand, during wet seasons the charge values would decrease. Although the latter situation would be welcome by the users, negative reactions to the former could be expected. Expressions include refusal to pay charges and clandestine abstraction attempts, since abstractions increase during dry seasons. Thus, this criterion presents a potential for inducing second-order conflicts which is either Low (wet seasons) or Very High (dry seasons).

3.7 Modeling the Residential Groundwater Supply Conflict

The conflict over residential groundwater supply in João Pessoa city (mentioned in Sect. 3.4) is the most expressive first-order conflict detected in the study area and demands the implementation of management instruments to discipline groundwater use. In order to evaluate the users' acceptability to this implementation and to verify the conditions that could support conflict resolution, the Decision Support

System GMCR II (Hipel et al. 1997; Fang et al. 2003a, b) is used to model the conflict. The GMCR II implements the Graph Model for Conflict Resolution (Fang et al. 1993), an abstract game model mathematically based on Game and Graph Theories, which furnishes a systematic structure for describing a conflict in terms of decision-makers, their options, and their preferences, and can point out the most likely resolution (equilibrium) to the conflict; besides, the interpretation of results can provide important information to assist in decision-making.

The conflict is modeled considering the consequences of adopting criteria, firstly, for applying water permits in order to reduce abstractions, and secondly, for applying bulk water charges to induce rational groundwater use. In both cases, the three decision-makers represent all the sectors involved in the conflict: (1) AESA—Water Management Agency of the State of Paraíba, the state water manager responsible for granting water permits, collecting bulk water charges, monitoring water uses, and punishing infringers, among other attributions; (2) CAGEPA—Water Supply Company of the State of Paraíba, to whose water distribution network all the city's apartment condominiums are connected; and SICON—Residential Condominiums Union of João Pessoa, an entity which represents a large number of residential apartment owners. Tables 3.3 and 3.4 indicate the decision-makers (DM) and their options, respectively for water permits and bulk water charges modeling. For water permits modeling, from the possible 64 (2^m) states, the states where AESA selects more than one option or doesn't select any option were excluded; thus, 20 feasible states remained. For bulk water

Table 3.3 Water permits modeling: decision-makers and options

Decision-makers (DM)	Options (m)
AESA (DM1)	1. Maintains its current water permits system but legalizes clandestine wells
	2. Applies restrictions to granted water permits and grants new restricted ones
	3. Maintains the existent water permits but does not grant new ones
	4. Suspends all the existent water permits and does not grant new ones
CAGEPA (DM2)	5. Accepts AESA's choice
SICON (DM3)	6. Accepts AESA's choice

Table 3.4 Bulk water charges modeling: decision-makers and options

Decision-makers (DM)	Options (m)
AESA (DM1)	1. Charges according to the state's current law
	2. Charges considering suggested criteria
CAGEPA (DM2)	3. Accepts AESA's choice
SICON (DM3)	4. Accepts AESA's choice

charges modeling, from the possible 16 states, the states where AESA selects more than one option were excluded; thus, 12 feasible states remained.

In order to determine the DM's preferences, the authors had interviews with key representatives of AESA (two directors and two technicians), CAGEPA (one director and two technicians), and SICON (one director and six members, all syndics and apartment owners in residential condominiums supplied by wells). The consequences of overexploitation and the suggested criteria were explained and AESA's options for both the conflict models were presented. Thus, the DM's preferences were attributed based on these interviewees' answers. For example, for water permits modeling, AESA is aware of its own organizational fragilities—which include an inadequate number of employees and the lack of financial/administrative autonomy in relation to the state government, and, consequently, hinder effective monitoring/punishing capacity—and its most preferable state is the one where option 1 is selected and accepted by all the other DMs; this is also SICON's most preferable state, since the status quo is just slightly modified; CAGEPA doesn't agree to the condominiums private groundwater supply and its most preferable states are those where option 4 is selected by AESA, independently of SICON's acceptance. For bulk water charges modeling, AESA's most preferable states are those where option 1 is selected and accepted by at least one of the other DMs, while its least preferable states are those where all the other DMs don't accept the option (1 or 2) selected and the status quo (where neither option 1 nor option 2 is selected[2]); CAGEPA's most preferable states are those where option 2 is selected, independently of SICON's acceptance, while all the other states are equally and less preferred; SICON's most preferable state is the status quo, followed by those states where options 1 and 4 are selected, and its least preferable states are those where option 2 is selected.

The results indicate that: (1) for water permits model the equilibria most likely to be maintained in the long run are state 1 (where AESA selects option 1 and CAGEPA and SICON accept) and state 5 (where AESA selects option 2, CAGEPA doesn't accept, but SICON accepts). Hence, the conflict solution demands, especially, SICON's acceptance in order to allow effectiveness for the criteria implementation; (2) for bulk water charges model, the equilibria most likely to be maintained in the long run are state 7 (where AESA selects option 1 and CAGEPA accepts, but SICON doesn't accept), state 9 (where AESA selects option 1, CAGEPA doesn't accept, but SICON accepts), and state 11 (where AESA selects option 1, and CAGEPA and SICON accept). Thus, the conflict solution hinders the criteria implementation; (3) in both cases the equilibria confirm the results obtained from criteria analysis (Sect. 3.6) and indicate that the criteria potential for inducing second-order conflicts ranges from High (for water permits) to Very High (for bulk water charges).

[2] Bulk water charges are not being applied yet, although the Decree 33613/2012 has been approved.

3.8 Mitigating Measures

By definition, mitigating measures to avoid or minimize second-order conflicts occurrence imply in the ability to eliminate the sources for failures in introducing water management measures. Groundwater use patterns currently observed in the study area constitute the major indicator of the state water manager's organizational fragility. For example, numerous clandestine wells, out of date water permits, unknown abstraction rates, among other distortions, highlight the urgent need for updating groundwater use information, renovating water permits, and taking wells out of clandestineness.

Hence, the first suggested mitigating measure is a reliable water information system to support the granting of water permits and the application of bulk water charges, facilitating the monitoring tasks. This means, in other words, the effective implementation of the fifth management instrument established by the Brazilian National Water Policy. The process of developing such an information system, in turn, requires the strengthening of the state water manager's organizational capacity, especially in terms of increasing the number of qualified employees/equipments to improve the agency's monitoring capacity.

Secondly, the attractiveness of public water supply in comparison to private wells could be augmented—if the state water supply company diminished the number of failures in meeting demands, minimized leakages and clandestine connections, and reviewed (and lowered) its tariffs—in order to stimulate its use and diminish groundwater exploitation.

Thirdly, as the use of the Decision Support System GMCR II pointed out, another aspect to be corrected is the high rejection the users present in relation to the suggested criteria, and, even, the very implementation of groundwater management instruments. The interviews made clear the users' lack of knowledge about groundwater specificities, the state water legal framework, and the role played by the components of the state water resources management system, among which is the state water manager (AESA). Publicity campaigns or education programs, among other tools, can enlarge the users' consciousness and increase the acceptability of groundwater management instruments and criteria.

3.9 Conclusions

This paper focused on groundwater management practiced in the Coastal Sedimentary Basin of the Paraíba River Lower Course Region. Unsustainable patterns of groundwater use are expressed by problems such as interference among wells, salt water intrusion, water contamination/pollution, among others, and reduce groundwater availability (first-order scarcity induced by demand). These problems occur more intensely in relation to residential groundwater supply in apartment condominiums along the coastal area of João Pessoa city, and characterize a first-order conflict over groundwater use.

The analysis of thirteen criteria, for applying water quality guidelines, water permits, and bulk water charges to groundwater management, indicated their high potential for inducing second order conflicts, due to the restrictions applied to existent/new water permits and/or the increases in bulk water charges values. Such conflicts are mainly expressed by the clandestine use of groundwater and the users' refusal in paying charges.

The Decision Support System GMCR II was used to model the conflict over residential groundwater supply in João Pessoa city. Besides confirming the results obtained from criteria analysis, the modeling/analysis process provided a better understanding on the decision-makers preferences, and the outputs indicated the importance of the users' acceptance to allow the criteria implementation.

Although the suggested criteria are very necessary for adequate management instruments to groundwater specificities, the results highlight the need for mitigating measures—which necessarily should support the state water manager's organizational strengthening, especially in relation to its monitoring/punishment capacity; public water supply attractiveness, by reducing supply failures and tariffs, in order to diminish groundwater exploitation rates; and the increasing of groundwater user's consciousness in order to augment criteria/management instruments acceptability—to allow the effective implementation of groundwater management in the Paraíba River basin, Brazil.

Acknowledgments The authors gratefully acknowledge: Drs. L. Fang, K.W. Hipel, D.M. Kilgour, and X. Peng for allowing them to use the DSS GMCR II; CAPES/PNPD (Post Doctorate National Program) for supporting the first author's scholarship; the ASUB Project (FINEP/MCT/CT-HIDRO), and the interviewed representatives of AESA, CAGEPA, and SICON, for providing important information to this research.

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Chapter 4
Paying to Conserve Watershed Services in Pangani River Basin, Tanzania

Makarius C.S. Lalika, Patrick Meire and Yonika M. Ngaga

Abstract Human beings depend on the integrity of watersheds to provide ecosystem services (e.g., water) that they need for their survival. The current watershed degradation represents the most serious threat to the provision of watershed services. The worldwide demand for integrated approaches to provide solutions to water flow reduction represents a significant shift towards management focussed on the sustained use of water catchment areas. This paper reports the findings of a study that was carried out to explore the potential for paying for the management of watershed areas in the Pangani River Basin in Tanzania. Site visits enabled the collection of hydrological data, and documented reviews and structured questionnaires were used to collect socioeconomic data. MS Excel was applied in drawing figures. We found that the minimum and maximum quantities of water discharge were 11,300,365 and 15,839,833 m^3 and 7,787,600 and 8,602,361 m^3 in Arusha and Moshi, respectively. Similarly, the minimum and maximum revenue collections from water users were €987,766, 60 and €1,659,160, 71; and €920,916, 40 and €1,456,075, 49 as projections and actual revenue collection, respectively. We conclude that water supply problems are caused by watershed degradation and obsolete water infrastructures. We recommend the integration of payment for watershed conservation approaches into watershed management to enhance sustainable water flow.

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_4

Keywords Watershed degradation · Water flow · Ecosystem services · Forest cover · Conservation

4.1 Introduction

Many ecosystem services (ES) from watersheds have gained attention in recent years across the entire globe (De Groot 1994; Pattanayak and Kramer 2001; Pattanayak 2004). Governments, international conservation organisations, private firms, and individual firms are progressively paying attention to the value of the innumerable ES provided by these watersheds (Krishnaswamy et al. 2006; Lopa et al. 2011). This awareness has drawn attention to the economic benefits of intact ecosystems and conservation initiatives, which had been taken for granted until recently (Pagiola et al. 2002; Lalika et al. 2011).

Increase of human population and pressure on watersheds in recent years (MEA 2005; Lalika et al. 2011) in search of ES is to blame for degradation of the resource base (Egoh et al. 2012). The current conservation and incentive structures for sustainable conservation of watersheds across the globe have rarely motivated the upstream communities who pay the opportunity cost for watershed conservation (Panayotou 1994; Costanza et al. 1997; Daily et al. 2000; Landell-Mills and Porras 2002; MEA 2005). As a result, land uses that provide watershed services are rarely enhanced at a socially and economically optimal scale, marginal upstream landowners continue to remain poor, and the downstream water users are gradually facing water supply fluctuations.

As in elsewhere around the globe, watersheds in the Pangani River Basin (PRB) are currently facing environmental degradation, due to the lack of sustainable approaches to conservation (Kulindwa 2005; Mwanyoka 2005; Turpie et al. 2005; Sotthewes 2008; Notter 2010; Lalika et al. 2011). Kilimanjaro Mountain, for instance, which is located within the PRB, is facing rampant environmental degradation to such an extent that even the distinctive snow at its peak is projected to disappear completely by 2020 (Kamugisha 2009). Environmental changes to the mountain through anthropogenic activities have contributed to the inefficiency of watersheds to supply water downstream (Kulindwa 2005; Ngana et al. 2010; Notter 2010; Msuya 2010). For PRB residents, their livelihoods, quality of life, community and children's health, and ultimately, the ability to survive are dependent upon effective watershed and water management. Degradation of watersheds means water scarcity and the emergence of conflicts among water users (Mbonile 2005).

Water shortages especially during the dry season contribute to hydroelectricity production fluctuation, resulting in power cuts. The three hydroelectric power plants located along the PRB contribute up to 17 % of the country's power capacity, which is mainly from hydropower (Ngana 2001; IUCN 2007). Power production at Nyumba ya Mungu Dam (NyD), the biggest reservoir for hydropower generation in the PRB, and its sister hydroelectric power plants (Hale and New Pangani) rely on water from the PRB watersheds. Recent studies carried out in the PRB (Ngana et al. 2010; Notter 2010; Msuya 2010; Lalika et al. 2011; Hellar-Kihampa 2013) indicated that there is a need for direct and innovative solutions for ecosystem conservation. Paying communities who reside in proximity to watersheds is perceived to be the ideal approach for sustainable watershed conservation (Muñoz-Piña et al. 2008; Cantor et al. 2012; Thatcher 2013).

While successful stories for payment for watershed services (PWS) implementation have been reported widely at global and local scales (Landell-Mills and Porras 2002; Pagiola et al. 2002; Pattanayak 2004; Pagiola et al. 2005; Pagiola 2008; Cantor et al. 2012), there is limited information on how PWS would be able to enhance watershed conservation in the PRB. Similarly, information on the amount of money to be set aside for watershed conservation is not known. Therefore, enhancing PWS as a policy option for watershed management in the PRB is crucial. Once the mechanism for benefit sharing and rewarding upstream communities for their involvement in watershed conservation is known, it will be easier to bring together sellers of ES (upstream communities) and buyers of the service (downstream water users). We carried out this study in order to identify and examine watershed conservation techniques that are in place in the PRB; to determine funds allocated for financing watershed conservation; and to document projected and actual revenue collection from downstream water users in the PRB.

4.2 Materials and Methods

4.2.1 Location and Description of Study Area

This study was conducted in four villages, namely, Kaloleni, Rau River, Chekereni and Lekitatu, along PRB, Tanzania (Fig. 4.1). The PRB extends from the northern highlands to the north-eastern coast of Tanzania. It lies between latitude 03° 05′ 00″ and 06° 06′ 00″ south and longitude 36° 45′ 36″ and 39° 36′ 00″ east.

The PRB is the largest river basin within the Pangani Basin (PB) and covers an area of about 43,650 km^2 (IUCN 2003). The terms “PRB” and “PB” have two different meanings. The former refers to the basin where the Pangani main river and its river tributaries are located, whereas the latter incorporates the PRB and the other three smaller basins, i.e., Umba, Zigi-Mkulumuzi and Msangazi (IUCN 2003; Faraji 2007; IUCN 2007). PB is a shared transboundary resource between Tanzania and Kenya (IUCN and PBWO 2008).

The PRB, which is the focus of this study, drains the southern and eastern sides of Mt. Kilimanjaro (5,985 m) as well as Mt. Meru (4,566 m), then passes through the arid Maasai Steppe in the west, draining some of the Eastern Arc Mountains (Pare and Usambara Mountains, which are World Biodiversity Hotspots) (Newmark 1998; Mwanyoka 2005; Mbeyale 2009), before discharging into the Indian Ocean at Pangani Estuary. The PRB hosts an estimated 3.8 million people, 80 % of whom rely directly or indirectly on irrigated agriculture for their livelihoods (IUCN 2007; IUCN and PBWO 2008; Kamugisha 2009).

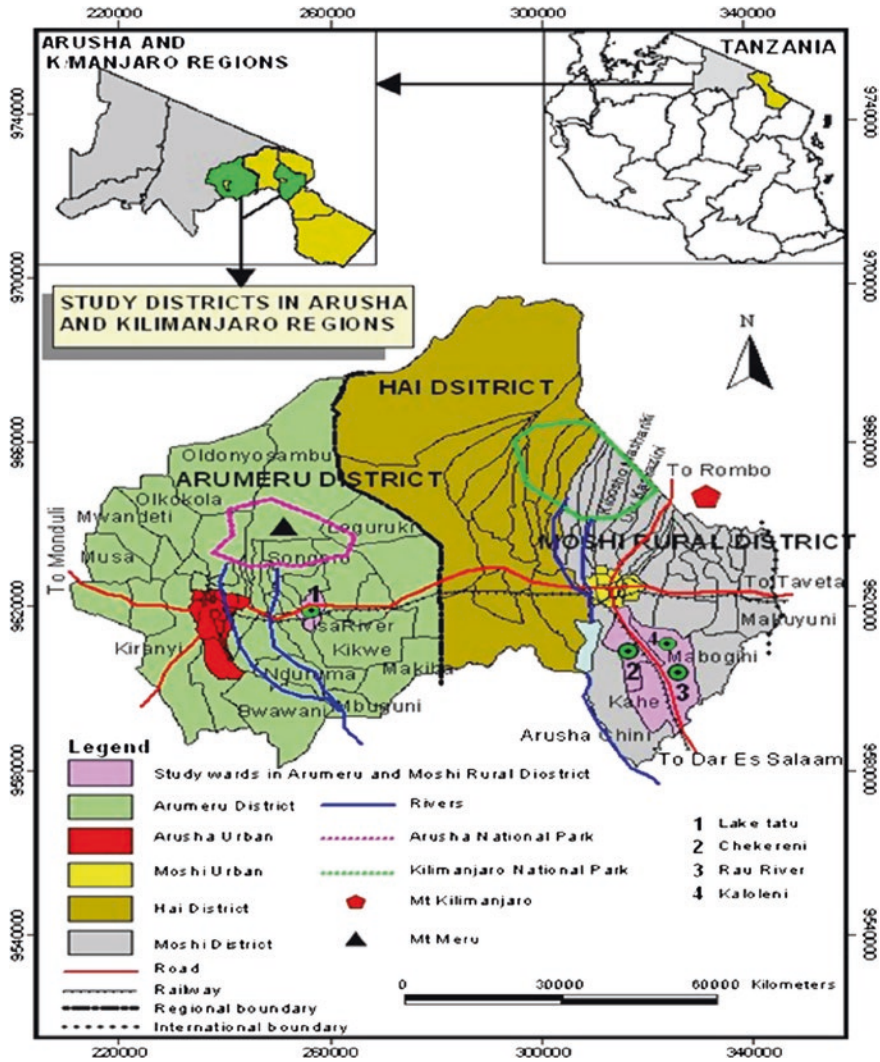


Fig. 4.1 Location of the studied villages in Pangani River Basin, Tanzania

Vegetation in the PRB ranges from forests on mountain slopes, to semiarid grasslands (IUCN 2003). The major vegetation types include forests, woodlands, bush lands, grassland thickets and plantation forests (Turpie et al. 2005). Excessive forest utilization has led to forest degradation and previous studies show that the natural forest in the Kilimanjaro region declined by 41 km^2 between 1952 and 1982 (Lambrechts et al. 2002). The main causes of forest degradation and deforestation include encroachment for settlement and agricultural, and increasing demand for forest products (mainly timber and fuel wood) (IUCN 2003).

Table 4.1 Total number of households sampled for questionnaire interviews

Village	Total households	Sample size	Sampling intensity (%)
Kaloleni	490	49	10
Rau River	340	34	10
Ckekereni	550	55	10
Lekitatu	250	25	10
Total	1630	163	10

4.2.2 Research Design and Sampling Procedure

We used a cross-sectional design as suggested by Casley and Kumar (1988) and de Vaus (1993) to execute field activities. The design allowed us to collect information at one point in time. To avoid bias in choosing respondents for our questionnaire survey, we adopted a simple random sampling technique. This technique allowed us to select respondents from the entire population in such a way that every member of the population had an equal chance of being selected. The sampling frames for this study were the village registers containing the lists of all households in the respective villages. The sampling units for our study were households, because household are where all decisions are made with the head of the household being the ultimate decision maker. In each village, we randomly selected households using a table of random numbers by matching their numbers in the register books. Within each of the identified four villages, a random sampling technique was adopted to identify respondents, and 10 % of the total households in each village were selected for interviews. Due to the variations of total population in the study villages, 10 % of all households was adequate to get a representative sample for our study. Therefore, a total of 163 household heads were sampled as indicated in Table 4.1.

4.2.3 Data Collection Methods

We executed this study in two main phases to collect both primary and secondary data. During phase one, we carried out a reconnaissance survey with the aim of familiarizing ourselves with the study area, pre-testing questionnaires and selecting study villages. Questionnaire pre-testing is an essential step for socioeconomic studies not only for checking the validity and reliability of the questions, but also for identifying weaknesses, ambiguities and/or omissions necessary for the main study.

In phase two, we collected socioeconomic data in the four villages using a structured questionnaire as the main field tool. We also used writing pads to document interesting and useful information from respondents whenever appropriate. During this research phase, we also carried out field excursions to identify the location of spatial features (such as springs, rivers, wetlands, dams and swamps/marshes); catchment forests; and irrigation farms. During field excursions, we conducted formal and informal interviews in order to attain insights on watershed services in the PRB. We collected data on water discharge from gauging stations after every hour for twenty-four hours. We also consulted response officers from the Arusha Urban Water and Sewerage Authority (AUWSA) and Moshi Urban Water and Sewerage Authority (MUWSA) for more data and information on water discharge and production.

Moreover, we collected secondary data from relevant published and unpublished reports. This information was collected from regional and district water authorities (e.g., AUWSA and MUWSA), Pangani Basin Water Office (PBWO) and the International Union for Nature Conservation (IUCN) Water and Nature Initiative (WANI) project. We conducted a literature survey and review in order to understand the water flow situation and supply and the efforts made so far by different actors for watershed conservation in the PRB. Various reports for studies conducted in the PB were also extensively reviewed. They include River Health Assessment Final Report (PBWO and IUCN 2007); Pangani Basin: A Situation Analysis Volume 2 (PBWO and IUCN 2009a); Pangani River Basin Flow Assessment: Basin Delineation Final Report (PBWO and IUCN 2008a); Development of Climate Change Scenarios (PBWO and IUCN 2008b); and Hydroelectric Power Modelling study (PBWO and IUCN 2009b). Key issues during secondary data collection include water supply, quantity of water sold, budgets for watershed management, revenues from water sales, water user payment mechanisms, main water users, and problems related to water flow, just to name a few.

4.2.4 Data Analysis

Later on the 163 structured questionnaires were coded, cleaned, categorized and transformed to enable analysis. Quantitative data (collected through the structured questionnaires) were analysed using Statistical Package for Social Sciences (SPSS) version 12.0. Multiple analysis was carried out to obtain frequency and percentages of responses from respondents, and tables were constructed. Data on quantities of water production, revenue projections and actual collection for water utilization were summarised, and MS Excel was used to draw figures based on the data. Before being used in MS Excel, information related to finances were converted from Tanzanian shillings (Tshs) to Euros (€). The exchange rates used is: 1€ = 2,273 Tshs.

4.3 Results

4.3.1 Watershed Management Techniques

We found that water control and decision-making with respect to watershed management are guided by various local approaches and different management techniques in the study area. As indicated in Table 4.2, building concrete walls/canals

Table 4.2 Watershed management techniques in PRB, Tanzania

Activity	Frequency (n = 161)	Percentages (%)
Building concrete walls/canals	148	92
Retaining riparian vegetation/trees	137	85
Planting trees	136	85
Uprooting weeds and removing muds in water canals	130	81
Removing muds and weeds in water sources	131	81
Total responses	682[a]	424[a]

[a]The total responses for frequency (682) and percentage (424 %) are greater than 161 and 100 %, respectively, due to multiple responses

(92 %); retaining riparian vegetation (85 %); tree planting (85 %); uprooting weeds and removing muds in water canals (81 %); and removing muds in water sources (81 %) are the water management methods that are in place in the study area.

From the table above it is evident that almost all techniques are applied in watershed management as the range between the techniques with the highest and lowest score is just 11 %. Nonetheless, from an ecological point of view, retaining riparian vegetation and planting trees are favourable techniques for watershed management because they have multiple benefits as far as watershed functioning and delivery of ecosystem services is concerned. Some of the retained trees in their natural habitats (e.g., *Rauvolfia caffra*, *Melicia excelsa* and *Ficus sycomorus* and varieties of *herbs* species) control soil erosion, purify the air, and serve as habitats for wild animals.

4.3.2 Water Supply and Sale for Domestic Uses

Analysis of water discharge indicated that Moshi had high figures in terms of maximum and minimum water discharge as compared to Arusha (Fig. 4.2).

The minimum and maximum quantity of water discharged in the study sites is 11,300,365 and 15,839,833 m^3 and 7,787,600 and 8,602,361 m^3 in Moshi and Arusha, respectively. In both cases, sources of water for domestic use are natural springs and bore holes. We found that water sources for Moshi town are from *Shiri* and Nsere springs and two boreholes, namely Mawenzi, Kilimanjaro Christian Medical Centre (KCMC) and Karanga. MUWSA is the government agency responsible for water abstraction, water infrastructure development and water supply in Moshi town. Like MUWSA, AUWSA is the government agency responsible for water abstraction, water infrastructure development and water supply in Arusha town. AUWSA has a mandate of managing water sources for Arusha town. These sources include Masama, Oldadae, Olesha and Midawe springs; and Sekei, Sanawari, Ilboru, Ilkieri and Sakina boreholes.

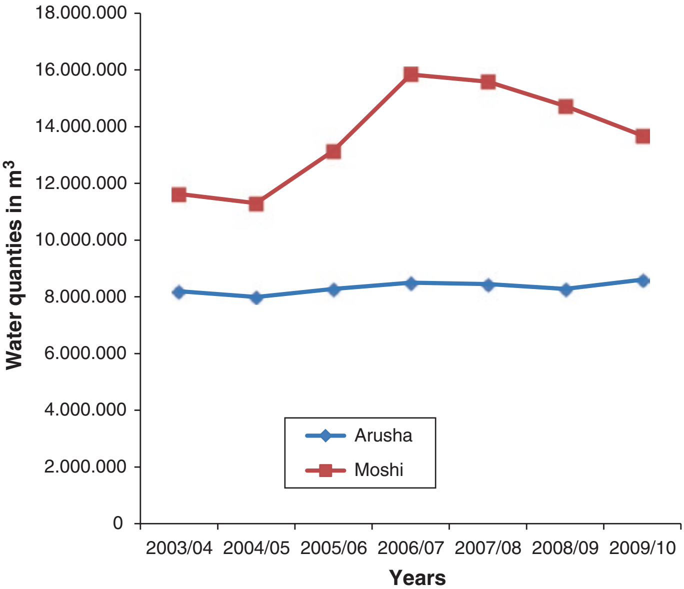
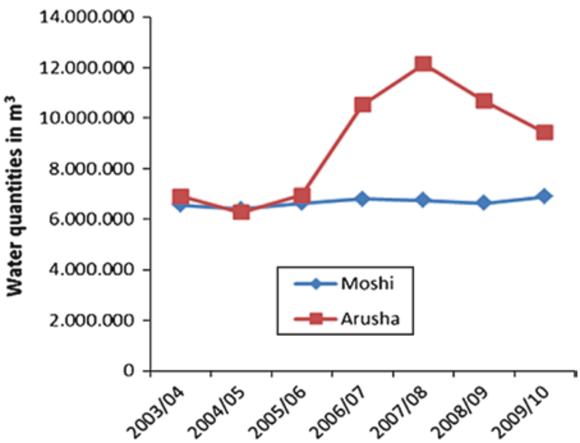


Fig. 4.2 Water discharge from 2003/2004 to 2009/2010 in Moshi and Arusha, Tanzania

We also documented the total quantity of billable water (i.e., water expected to be sold). We found that the highest quantity of billable water for the 2009/10 financial year in Moshi and Arusha was 6,881,888.8 and 12,135,143 m^3, respectively (Fig. 4.3).

Findings for billable water indicated that minimum quantities were 6,396,876 and 6,265,965.96 m^3 for the financial year 2004/2005 for Moshi and Arusha, respectively. The low quantity of billable water is attributed to water leakage while on transit; obsolete water pipes that burst due to high pressure; illegal water abstraction; poor meter reading and deliberate destruction of water pipes.

Fig. 4.3 Quantity of billable water from 2003/2004 to 2009/2010 in Moshi and Arusha,Tanzania



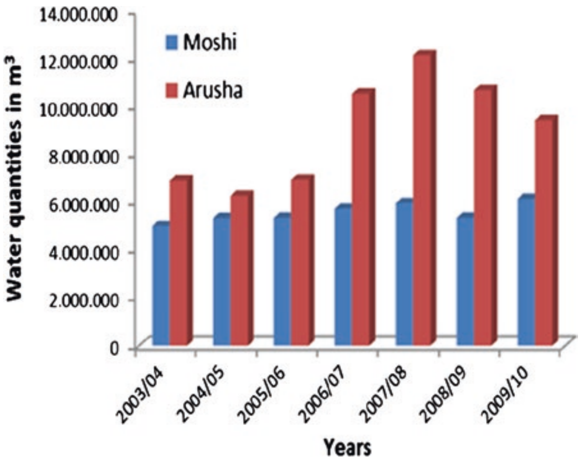


Fig. 4.4 Quantity of water sold from 2003/04 to 2009/10 in Moshi and Arusha,Tanzania

4.3.3 Quantity of Water Sold

Our findings on the quantity of sold water indicated that there was an increase from 5,004,853 to 6,140,488 m^3 for the 2003/2004 and 2009/2010 financial years, respectively, in Moshi town. Similarly, we observed an increase of water sold from 6,265,966 to 12,135,143 m^3 for the 2004/2005 and 2009/2010 financial years, respectively, in Arusha (Fig. 4.4).

We also found that the gap between billable and sold water is caused by water leakages while in transit either to the central tanks for storage or by illegal abstraction. However, a number of standing community water taps are fixed in villages where water pipes cross from watersheds to users downstream. This is a direct incentive for local community involvement in sustainable watershed conservation. In other words, this forms the basis for water users to realise the benefit of watersheds and to be convinced to pay for their conservation. In both cases, Arusha had a higher quantity of sold water than Moshi. This trend is similar to of billable water, shown in Fig. 4.3.

4.3.4 Financing Watershed Management in PRB

4.3.4.1 Budget Allocated and Amount Received

With respect to financing conservation programmes, we found that watershed management is not given outstanding priority as compared to social services sectors (e.g., health, education, roads, etc.), which is why the amount donated for watershed conservation is less than what was projected (Fig. 4.5).

As indicated in Fig. 4.5, the PBWO (the sole and mandatory institution that collects water user fees) had projected budgets of €159,490, 62 and €329,665, 85 for the

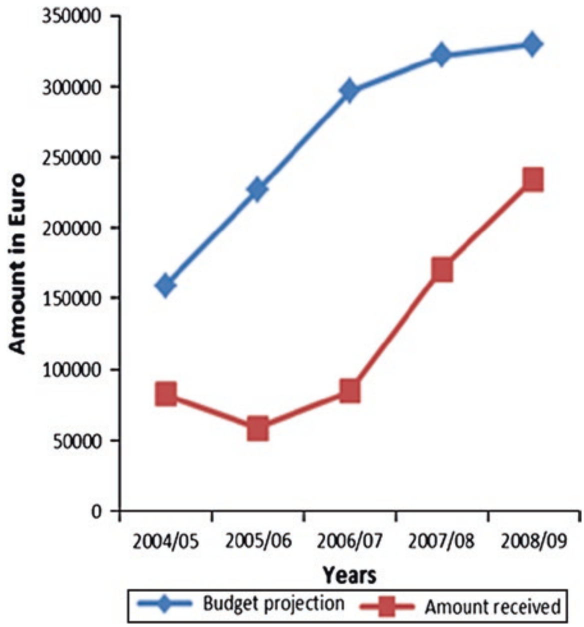


Fig. 4.5 Fund allocation for financing watershed conservation between 2004/05 and 2007/08 in PRB, Tanzania (*Source* PBWO database, 2009). Exchange rate used: 1€ = 2,273 Tshs.

2004/2005 and 2008/09 financial years, respectively. Surprisingly, only €82,693,72 and €234,537,77 were made available for the 2004/05 and 2008/09 financial years, respectively (Fig. 4.5). Potential sources of the budget include water user fees from Tanzania Electricity Supply Company (TANESCO), Ministry of Water and Irrigation (MoWI), other water user fees (from industries, small- and large-scale irrigators, water abstractors, domestic users), and water right application fees.

4.3.4.2 Projected and Actual Revenue Collections

We were also interested in finding out the projected and actual revenue collected from water users in the PRB. Findings indicated that projections were €987,766, 60 and €1,659,160, 71 for the 2004/2005 and 2009/2010 financial years, respectively, whereas the actual collection was €920,916, 40 and €1,456,075, 49 for the 2004/2005 and 2009/2010 financial years, respectively (Fig. 4.6).

Contrary to finances for watershed management where the budgets were not attained in any financial year, there is an exception for projected and actual revenue collected. As indicated in Fig. 4.6, the actual collection for 2003/2004 was greater (€1,074,874, 81) than the projected collection (€987,766, 60). This might be attributed to efficiency in user fees collection, or motivation given to employees in charge of water revenue collection, just to name a few.

As in Fig. 4.6 above for Moshi town, the actual collection in Arusha town (Fig. 4.7) was less than the projected collection with the exception of 2003/2004 and 2004/2005 where the actual collection was greater than the projected collection.

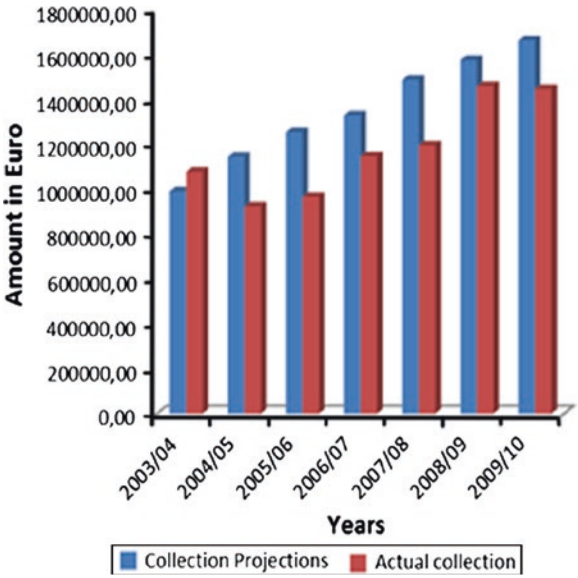


Fig. 4.6 Revenue collection from 2003/2004 to 2009/2010 in Moshi, Tanzania. Exchange rate used: 1€ = 2,273 Tshs.

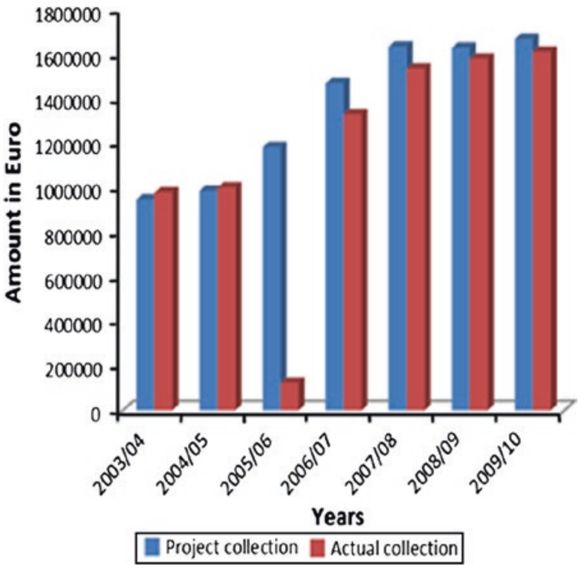


Fig. 4.7 Revenue collection from 2003/2004 to 2009/2010 in Arusha, Tanzania

The reason for the actual collection surpassing the projected collection might be attributed to efficiency in the whole process of revenue collection. Nonetheless, we found a shocking fall in the actual collection compared to the projected collection in the 2005/2006 financial year (Fig. 4.7). The reason for this dramatic fall in actual collection might be due to drought, poor water infrastructures (pipes), inefficiency of personnel responsible for revenue collection, and, of course, little water flow caused by the degradation of the watershed ecosystem upstream. If revenue collection increases due to payment from water users, a certain percentage could be diverted to finance forest conservation which might result in more water availability in the long run.

4.4 Discussions

4.4.1 Water Resource Management Techniques

As indicated in Table 4.2, concrete canals were preferred by a majority of smallholder irrigators on the ground that concrete canals prevent water infiltration as water flows downstream. Their preference for concrete canals may be attributed to their desire for sufficient water irrigation. From an economic perspective, water is an essential input for production in primary, secondary and tertiary sectors, as well as for household consumption (UNESCO 2006).

However, stakeholders in the study area seemed to focus more on the economic benefits of water rather than the ecological aspects. In view of this reality, Zoumides and Zachariadis (2009) contend that although water pricing is potentially an effective tool in terms of economic efficiency, its environmental effectiveness is not guaranteed; thus, it may not drastically improve water resource management.

Retaining riparian vegetation (85 %) and tree planting (85 %) were also applied as water conservation methods as well as to enhance ecological integrity. Various studies (Costanza et al. 1997; De Groot et al. 2002; Krishnaswamy et al. 2006; Notter 2010) have indicated that natural vegetation has the potential to offer hydrological functions including groundwater recharge; water quality improvement; regulating the timing and extent of runoff; storing water; reducing salinization; filtering and decomposing organic material; and many more. These hydrological functions and services are particularly important for enhancing sustainable water flow in the PRB either because rainfall is highly seasonal or locally limited, or because intensively cultivated and densely populated agrarian landscapes downstream are affected by soil-hydrological processes in the watersheds. Thus, the advantages of watershed conservation through ecological approaches (i.e., retaining natural vegetation) are innumerable. Apart from enhancing water flow, ecological conservation approaches enhance watersheds to provide multiple ES and regulate ecological functions (Cheng et al. 2002; Lu et al. 2001; Muñoz-Piña et al. 2008; Pattanayak 2004).

4.4.2 Water Production and Supply

Water supply in PRB depends mainly on natural flow from various springs, boreholes and rivers originating from Kilimanjaro and Meru Mountain watersheds.

Frankly speaking, water supply in Moshi and Arusha towns is not sufficient and MUWSA and AUWSA, the legal water abstractors, are yet to fulfil customers' demands. Sustainable water supply is crucial in the area and MUWSA and AUWSA are trying their best to accomplish this.

The current watershed degradation and reduction of water (Notter 2010) is attributed to the lack of a holistic/integrated approach towards watershed management (Msuya 2010). Ngana (2001) asserts that ineffective enforcement of conservation laws, climate change, population growth, socioeconomic and political changes and lack of an effective institutional framework contribute to the decrease in water in the basin.

Increased population in the basin, coupled with economic activities requiring water as an input such as hydropower generation, irrigated agriculture, industries, tourism, mining, livestock keeping, domestic uses, fisheries, wildlife and forestry activities, has further aggravated the situation (Mbonile 2005). Water scarcity is a problem in many places due to unreliable rainfall, multiplicity of competing uses, degradation of sources and catchments (Faraji 2007; Kulindwa 2005; Turpie et al. 2005, 2007). Mbonile (2005) found that water scarcity threatens food security, energy production and environmental integrity and, consequently, there are water use conflicts between various water actors, including communities and conservationists; upstream and downstream users; hydroelectricity producers and other users; communities and donor agencies; farmers and pastoralists; rural and urban areas; and communities and river basin authorities.

Comparing the quantities of billable water and sold water for Moshi and Arusha, the quantity of billable water presented in Fig. 4.3 is higher for both of the towns than that of sold water displayed in Fig. 4.4. This might be due to the differences in efficiency of workers and the level of water infrastructures. In fact, intact and good water pipes retain much more water than obsolete water pipes. Other reasons for the differences are that water users in Arusha might be more civilised and, therefore, they do not abstract water from pipes illegally while it is on transit to reservoirs and storage tanks.

4.4.3 Financing Watershed Management and Revenue Collection in PRB

Despite being stipulated clearly in the Tanzania National Water Policy (URT 2002) on integrated water management and the need to finance catchment areas for sustainable water flow, little has been done on the ground in PRB. For quite some time, watershed management in Tanzania has been financed by the World Bank through the Ministry of Natural Resources and Tourism (Forestry and Beekeeping Division) and District Natural Resource Offices. In some cases, international conservation organisations such as World Wildlife Fund for Nature Conservation (WWF), International Union for the Conservation of Nature (IUCN), CARE International and other local conservation organisations have been in the forefront in addressing the need for conserving critical watershed areas.

On the other hand, setting aside funds for nature conservation has been quite a problem in PRB. This is attested by Fig. 4.4 which indicates that the minimum budget for watershed management was €159,490, 62 while the actual amount of money given was merely €82,693, 72. Similarly, the maximum budget was €329,665, 85 while the actual amount collected was €234,537, 77. This implies fees for water utilization are not properly dealt with and this finding is in line with that of Turpie et al. (2005), who found inefficient collection of fees from water users.

Furthermore, lack of sufficient quantity and quality of manpower, and skilled and committed personnel; poor water infrastructures; energy (electricity) fluctuation; and low capacity of the watershed to produce water, are among the factors leading to low revenue collected from water users. As portrayed by Fig. 4.5, only €1,456,075, 49 was collected as revenue from water users, while the projected collection was €1,659,160, 71 for the 2008/2009 calendar year. Similar findings with regards to poor revenue collection in PRB are reported by Kulindwa (2005), Msuya (2010) and Turpie et al. (2005).

Despite the significant advances in scientific understanding of forest and water interactions, the roles of forests in relation to the sustainable management of water resources in PRB remains a contentious issue. Uncertainty, and in some cases confusion, persist because of difficulties in transferring research findings to different watershed scales, different forest types and different forest management regimes.

We also think that priorities and key decisions by policy makers have been geared towards financing social services for political gains at the expense of nature conservation. This may partially be due to the gap existing between research and practice. The policy gap, which persists at least in part because of a general failure to communicate results of hydrological research effectively to policy-makers and to challenge conventional assumptions with scientific evidence, also plays a key role.

If conservation initiatives are to be successful, deliberate efforts should be made to manage watersheds using a holistic approach. This can be achieved by integrating financial matters in water resource management, which could improve people's willingness to pay for and improve water supply in the long run. This is only possible, however, once water users are assured of sustainable water flow and supply.

4.5 Conclusions

Water supply in PRB is handicapped by a higher water demand than the watershed can provide. multiple water uses; rampant influx of water users in the area; electricity cut-off, especially where the water supply requires pumping; obsolete water infrastructures (e.g., water pipes) that cause water leakages before reaching downstream users; and lack of transparency in utilization of the collected revenues, just to name a few.

On the other hand, commitment for watershed conservation is still low among stakeholders in PRB and this is testified by the low revenue collected compared to the projected amount. The low amount of revenue collected is contributed to by the inefficiencies of the methods used during revenue collection. Retaining natural vegetation around water sources is by far the most sustainable ecological approach for watershed management and sustainable water flow in PRB as it has multiple benefits including ecosystem integrity.

As mentioned above, enthusiasm for financing watershed conservation in PRB is still low. This may be partially due to scepticism about misuse of contributions, lack of concrete plans on how to collect and utilize funds from water users, or lack of people's awareness of the clear link between conservation and increase of water availability. The current study is the basis for securing funds from downstream users for financing upstream communities, who are principally the guardians of watersheds. In addition, it is high time that a strategy be conceived that would incorporate the tourist sector in the payment for watershed services. Nevertheless, awareness and capacity building among water users is essential for sustainable watershed conservation through PWS. Therefore, it is crucial to increase the potential for the establishment of PWS schemes in PRB and in other river basins facing similar problems.

Acknowledgment The financial support for this work came from the government of Belgium (PhD scholarship, grant number 09TAN/5917) through the Belgium Technical Cooperation (BTC). Organizers of the 2013 ICWRER event deserve a special mention for their invitation in Koblenz, Germany which was the basis of this paper. Authors are grateful to research assistants Ms Mariam Ramadhani and Ms Mariam Muya, for their tireless efforts during field work. Anonymous reviewers are equally appreciated for their professional and constructive suggestions.

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Chapter 5
Economic Valuation for Decision Making on the Protection of Water Sources

Homero Castanier

Abstract The purpose of this paper is to carry out an economic analysis of the required investments for the protection of natural water sources for the drinking water supply of the city of Quito, Ecuador. Although "producing" water or minerals has no cost since they naturally exist on the environment, the values of ecosystems' services and functions can be estimated based on applications of a series of environmental economics methods. The Contingent Valuation Method is especially relevant, since it estimates the use and non-use values, which can correspond to the total economic value or benefits to society derived from protected water sources. This method is applied to a case involving the Water and Sanitation Company of the City of Quito (EPMAPS), which has made important investments for protection of the main water sources for the city of Quito. The results of the economic analysis demonstrate the economic feasibility of the required investments for the protection of water sources taking into account the costs involved and the total economic value or benefits calculated by means of the Contingent Valuation Method. This will allow its dissemination and training at all levels in order to internalize the environmental economic values on related individual and institutional decision making.

Keywords Water · Valuation · Sustainability

5.1 Introduction

Although world governments, through international agreements and protocols such as the United Nations World Summits on Environment and Development (UNCED, 1992 Río de Janeiro), Sustainable Development (WSSD, 2002

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_5

Johannesburg), Climate Change (COP 15, 2009 Copenhagen), or the Convention on Biological Diversity (CBD, 1992) and the International Trade Agreement (WTO, 1995) of the United Nations system, have increased the urgency for development based on ecological and economic sustainability, many development policies still conflict with the sustainable use of scarce resources. Funding for implementation of development projects provided by financing agencies are commonly evaluated by standard estimation and analysis of benefits and costs that arise from the proposed projects, based on the utilitarian theory of values determined by market prices and quantities, which do not account for environmental damages (or gains) in general, neither for resource depletion in particular (Pearce and Warford 1993: pp. 61–164).

Several evaluation systems for funding development and conservation projects are currently aimed at the integration of environmental economic values in the analysis. Through the Dublin Principles adopted by the 1992 Dublin International Conference on Water and the Environment, the international community has, at the highest political level, affirmed the notion that water is an integral part of ecosystems, and that it is a social and economic good whose quantity and quality should determine the nature of its utilization (Ramsar 2007). Tools are required to evaluate the benefits derived by societies from the goods and services provided by water ecosystems.

The Millennium Development Goal 7, "ensure environmental sustainability", targets to the integration of the principles of sustainable development into country policies and programmes and to reverse the loss of environmental resources. Some of its indicators refer to the proportion of total water resources used, protected areas, and access to adequate water sources. A sound water management system allows for the mobilization of economic resources to finance investment in the development and conservation of this resource (UN/ECLAC 2005).

Human welfare is so connected and dependent on the short-term inequitable behavior and patterns of the economic system that people tend to believe they are better-off exploiting the natural assets than by conserving them for long-term sustainable use (Pearce 1998: p. 23 and Dixon and Sherman 1990: pp. 1–5). This means that prices in the market system are the basis for allocating land, labor, and capital among producers, and goods and services among consumers without any consideration of values and of affected present or future third parties not involved directly in the market exchange (Breedlove and Joseph 1999).

More than 1,500 studies and papers from over 40 countries on many topics, including transportation, sanitation, health, the arts and education, as well as the environment (Carson et al. 1994, cited in Hanemann 1994) and involving the valuation of the provision of public goods as ecosystem's functions and services, have been carried out worldwide in the last three decades. A sample can be consulted in the paper Economic Valuation of Freshwater Ecosystem Services in the United States: 1971–1997 (Wilson and Carpenter 1999).

Recent institutional and legal frameworks have contributed to that effect, as the United States' National Environmental Protection Act of 1969, the posterior Clean Air Act, and Clean Water Act, and the Ramsar Convention Bureau for Wetlands that requires economic valuations of wetlands intending being part of its conservation and development program, just to mention a few. These studies have been accomplished with different degrees of scientific rigor and level of detail depending on the state-of-the-art of valuation theory and methodologies at the time when they were done or on the purposes of the valuations.

5.2 Principles for Natural Resources Valuation

A key concept on the economic valuation of natural resources like source water, is the total economic value of environmental resources and services, which has to be developed based on different valuation approaches and benefit measurement. As will be explained in detail in the next section, the total economic value is the sum of the use and non-use values. *Use value* is the value derived from the direct or indirect actual use of a good or service (wood, food, raw materials, hunting, fishing, hiking, or water and climate regulation), includes the option and bequest values to use or not something in the future.

Non-use values are values that are not associated with actual use, or even the option to use a good or service. Consider for example the existence value of simply knowing that something exists, even if it will never be seen or used.

Modern trends of economic and environmental systems are characterized by increases in production and consumption, development of technology, and production or utility value on one side. Such changes are observed alongside scarcity of natural resources, pollution and environmental degradation. The close interrelations between economic and environmental systems are shown in Fig. 5.1.

Ecosystems' goods and services consist of flows of materials, energy and information of the reserves of natural capital that combine with services of the manufactured capital and human capital to produce human well being (Costanza et al. 1997). In Fig. 5.2 is presented a general scheme of ecosystems' services and functions.

The classification of the different types of goods are closely linked to their total economic value, as is detailed in Fig. 5.3, based on the characteristics of Rivalry and Excludability.

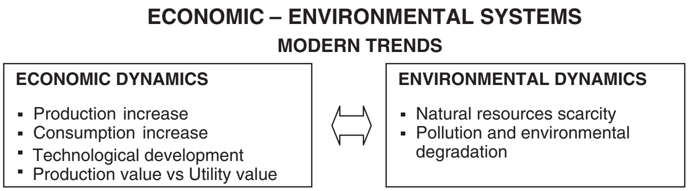

Fig. 5.1 Modern trends of economic and environmental systems (Adapted and adjusted from the conceptual framework)

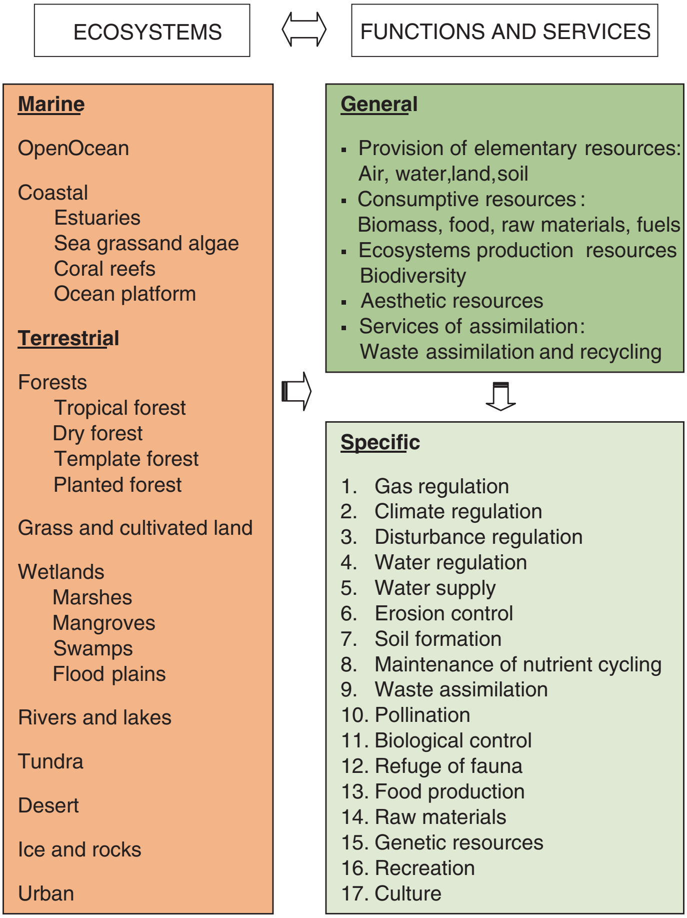

Fig. 5.2 Ecosystems' services and functions (Adapted and adjusted by the author)

Rivalry in consumption refers to the degree to which one person consuming a particular unit of a good or service precludes others from consuming that same unit of a good or service. *Excludability* refers to the possibility of preventing people (consumers) who have not paid for a good or service, from having access to it.

Water resources cannot be considered a public good, because their use by someone limits or diminishes its use by others, although it is a common resource, since its use cannot be prohibited. Common resources, like public goods, are not excludable. They are available free of charge to anyone who wishes to use them. Common resources tend to be used excessively when individuals are not charged for their use.

On the other hand, examples of public goods are the ecosystems, providing public services given their ability to underpin and buffer the market economy

TYPES OF GOODS

		Rival	
		High	Low
Excludable	High	**Private Goods** Cultivated or processed food Clothing Housing Vehicles	**Collective Goods** Fire protection. Cable TV Ungongested toll roads
	Low	**Common Goods or Resources** Clean air Clean water Oil fields Fishing, whales, wildlife, others Public parks	**Public Goods** Ecosystems (wetlands, oceans, others) (buffer impacts of production and consumption processes, and supply environmental services). National Defense. Basic research. Public Radio. Fireworks. Poverty reduction programs.

Fig. 5.3 Types of goods (Adapted and adjusted from the conceptual framework)

against external shocks of production and consumption, or wetlands acting as local public good by buffering economy from natural and man-made shocks by providing water purification and habitat services.

5.3 Valuation Approaches and Benefit Measurement

As many natural resources like water and some non renewable energy sources show signs of scarcity and predictable exhaustion horizons, the environment had started to obtain a status equivalent to that of an economic good. While many environmental goods like water and minerals have a price depending on their extraction and distribution costs, they are often not valued according to their production cost. "Producing" water or minerals has no cost, since they naturally exist on the environment. For this reason, the environment is outside the market, and environmental economics deals mainly with its monetary valuation, based on the application of instruments of economics and on the scientific knowledge of the biophysical and socioeconomic characteristics of the environment.

The discussion on environmental issues took force particularly in the 80's and 90's, when it became more evident that increase in production comes along with an intensification of environmental degradation (Chang 2005).

The efficiency analysis of economic investments and resource allocation, particularly in the public sector, has traditionally been done using a benefit-cost analysis approach (Pearce and Warford 1993: p. 164), in which the corresponding monetized benefits and costs involved are compared prior to deciding on an efficient policy choice, or determining liability when natural resources have been harmed or degraded (Bockstael et al. 1999: p. 3).

A sustained operation of the market depends upon the correct valuation and management of non-market goods such as those provided by the environment or via public expenditure. Benefit valuation comprises to make the best possible effort in calculating all the benefits and costs involved as a consequence of a policy choice no matter if they are part of well defined markets or if they are not marketed goods at all. This is reflected for instance in Executive Orders (Presidents Carter, Reagan, and Clinton) and various federal regulations of the United States as the Comprehensive Environmental Response, Compensation, and Liability Act (Portney 1994: p. 12).

The benefits from the provision of public goods arise from the value individuals assign (Brown 1984, cited in Mitchell and Carson 1989) to the services or functions they provide, as for example the value assigned to improvements in air visibility or water quality. Deficiencies in the services may be thought of as damages, the distinction being made based upon a reference level of the good (Mitchell and Carson 1989), which could be a maximum or minimum allowable limit, or a current state level.

The value of a good is the most an agent is willing to give up in exchange for the good out of the resource it controls (Mitchell and Carson 1989: pp. 20–21), and still be as well off as before the exchange of the good (in the case of a quantity increase). If the same level of utility or satisfaction is not maintained when the good is consumed, variations in levels of well-being will have to be taken into consideration for the estimation of the total value.

It is important to distinguish the differences between the following two concepts: (i) *Willingness to Accept* (WTA) is the minimum amount that a person is willing to accept to abandon a good or to put up with something negative, such as pollution, and (ii) *Willingness to Pay* (WTP) is the maximum amount an individual is willing to give up to procure a good or service or avoid something undesirable. This concept is used to measure benefits, since the points on the demand curve represent the amount of money some person is willing to pay for the last unit of the good.

This clearly means that an agent or society as a whole could never value a good or service by means of stated willingness-to-pay exceeding their actual ability to pay (Pearce 1998: pp. 25–26; Bockstael et al. 1999: pp. 8–9).

Eliciting people's preferences or willingness-to-pay and inferring from this information the true value of a good by means of alternative methods and markets is still a controversial issue due to biases and subjectivity of the results. In order to address these contested arguments, a series of considerations on methodological approaches for surveying people's preferences, as well as technical and statistical procedures have to be taken into account to obtain results as accurate as possible.

Economists recognize two main classes of value for environmental resources: use value (created directly or indirectly by the current use of resources) and non-use value (existence) (created by the desire to assure continued provision of the resource for others in the future). The total value is the use value plus the existence value. This total WTP can satisfactorily be used in most benefit-cost analysis (Mitchell and Carson 1989).

$$Total\ Economic\ Value = Use\ Value + Non{-}use\ Value$$

$$TEV = UV + NUV$$

A scheme of the total economic value of environmental resources and services, is represented in Fig. 5.4, while in Fig. 5.5, the main services of water resources are summarized.

On the process of valuing environmental services and public goods, the total economic value, which means the use values and non-use values, has to be estimated for the determination of total benefits and costs related to development

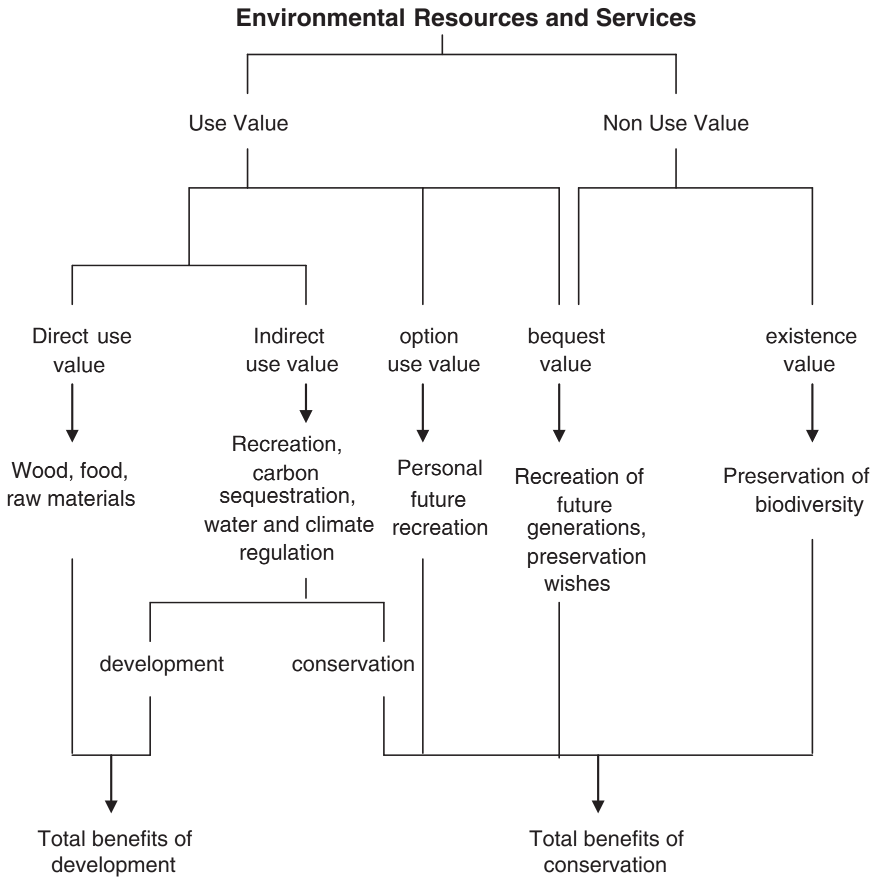

Fig. 5.4 Total economic value of environmental resources and services (Adapted and adjusted by the author)

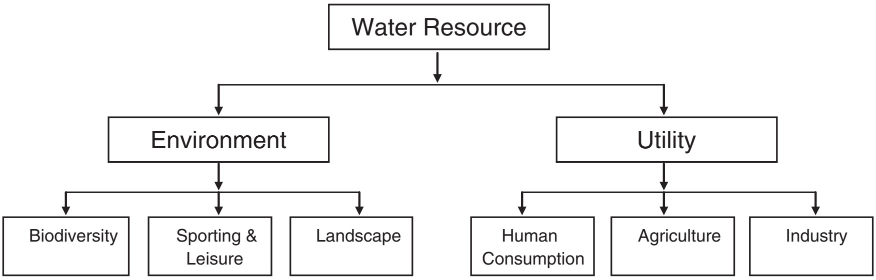

Fig. 5.5 Main services of water resources (Adapted and adjusted by the author)

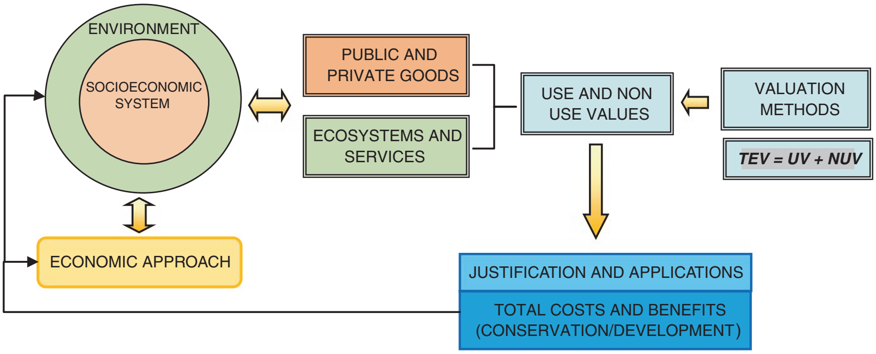

Fig. 5.6 Processes of valuation of environmental services and public goods (Castanier 1999)

and conservation actions. The results represent a relevant input for the interactions between environmental and socioeconomic systems, as presented in the diagram on Fig. 5.6.

5.4 Economic Theory on Natural Resources and the Contingent Valuation Method

The Contingent Valuation Method (CVM) constructs a hypothetical market to elicit the willingness-to-pay of the people surveyed. It is the only method that measures the option and existence values, and provides a true measure of the total economic value, although the results are sensitive to several biases in the design and application of surveys.

Eliciting the appropriate individuals' willingness-to-pay for public goods or environmental resources and estimating the aggregate value to society requires overcoming a series of complexities and limitations related to the gathering and processing of data, as well as economic and social analyses. Besides the advancement of neoclassical economic theory, welfare economics, and operational applications, economists, research scientists, and ecologists have devoted through the last three decades a great deal of time and resources in order to improve the methodological approaches for the economic evaluation of environmental services. These attempts to control for the limitations and biases of benefit measurement, as described by Mitchell and Carson (1989), and summarized below:

- Design, application, and assessment of benefit measurement methods
- Definition of the correct economic measures of consumer benefits
- Solutions proposed in order to deal with externalities as property rights regimes, uncertainty, as well as willingness-to-pay versus willingness-to-accept measures (compensations)
- Exhaustive systematization and classification of the full range of possible benefits
- Aggregation and distribution issues (aggregation of individual benefits, subcomponent aggregation, distribution of individual willingness to pay, and identification of all the potential beneficiaries of a given change)
- Appropriate survey design.

Extensive research done for the improvement of hypothetical/direct methods as the contingent valuation method, has allowed for their compliance with key properties of benefit measurement methods.

The creation and analysis of hypothetical and potential markets for public goods or ecological services is based on the principle of "(scientific) demonstration-capture" (Pearce 1998: pp. 23–24), in order to convert them into real benefits. On the other hand, people's preferences or individuals' willingness-to-pay for a change in a state has to be approached on the basis of marginal analysis since only small changes in the supply and demand of goods and services allow for prediction. The advanced set of theoretical basis and methodological tools can be applied and used as an important instrument for decision making insofar as its implementation by practitioners and researchers complies with its scientific principles on economics, social research, and natural resources. Otherwise, counteracting effects might occur, as a lack of credibility on the outcomes and on the integrity of the scientific method could mislead decision makers with erroneous information.

In Box 1 is summarized a basic model for estimations of the Willingness-to-Pay for improvements of water quality.

Box 1

Basic Model for Estimations of the Willingness to Pay (WTP) for Improvements in the Water Quality (Neuse River) (Whitehead 2003)

It is assumed that the consumers have the utility function $u(x,q,z)$, where x is the use of natural resources, q is a measure of the quality of the resource, and z is the composite of all the market goods. The expenditure function, $m(p,q,u)$ is found solving the consumer's problem:

$$\min(z + px) \text{s.t.}\, u = u(x, q, z) \textit{where p is the price of use and } pz = 1.$$

The utility function measures the minimum quantity of money that the consumer must expend to reach the reference utility level, and is incremental in p and u and decreases in q.
The Willingness to Pay (WTP) is the maximum quantity of money that the consumers would give up in order to enjoy an improvement in the quality. The Willingness to Pay for the improvement in the quality is

$$WTP = m(p, q, u) - m\left(p, q^{*}, u\right)$$

where q is a degraded level of quality and q^* is an improved level of quality. The expenditures to maintain the level of utility decrease with the increase in the quality, in a way that

$$WTP > 0$$

The value of water sources under regimes of conservation or improvement of water quantity, quality and flow regulation for water supply systems, can be determined by methods other than the contingent valuation, as the *opportunity costs* or *avoided costs*: (i) calculation of tariffs to be charged to downstream users as payment for preserving the upstream forests or land cover; (ii) estimation of additional drinking water treatment costs in the case of deteriorated raw water quality; or (iii) estimation of additional costs of investments on new water supply projects as the availability of water resources diminishes. However, for the application of these methods a series of uncertain assumptions have to be made in order to consider complex sets of variables involved, which may produce inaccurate results.

5.4.1 The Contingent Valuation Debate

Instruments of contingent valuation include consulting to individuals by means of experimental surveys about their personal valuation of increments or decreases of non marketed goods and services using contingent markets. Generally the debate on contingent valuation raises broad questions about what economists have to say about the values that individuals place on public or private goods. When attempting to infer values economists prefer evidence based on actual market behavior, whether directly or indirectly revealed. Thus a technique like the contingent valuation method, wherein values are inferred from individual's stated responses to hypothetical situations, has stirred a great deal of debate (Portney 1994: pp. 1–6) and parallel research.

Particularly important are the debate issues when natural resource damage assessment or estimation of lost existence value is involved in order to determine economic liability of the intervening parties. Portney (1994) presents a rather impartial overview, and Hanemann (1994) and Diamond and Hausman (1994) make cases for and against the use of the CV method, respectively. Because of its relevance, below follows a brief summary of the main guidelines of the NOAA's (National Oceanic and Atmospheric Administration—Department of Commerce, 1993) Panel regarding CV surveys.

5.4.2 Main Guidelines for CV Surveys

Given the magnitude of the values of damages produced by the Exxon Valdez oil spill and the controversy generated on the Contingent Valuation method, in 1993 the National Oceanic and Atmospheric Administration (NOAA/USA), organized a high level panel to answer the question "Is the Contingent Valuation a valid method to determine the lost economic value due to damages to natural resources?" The panel was integrated by several prominent economists, including two Nobel Prices, Kenneth Arrow and Robert Solow. Testimonies were presented from some of the most prominent supporters and critics of the Contingent Valuation method. The panel concluded that the CV method can produce reliable estimations, applying among others, the following general guidelines (Portney 1994):

- In-person surveys
- Should elicit WTP to prevent future incidents
- Should utilize the referendum format, since individuals are rather familiar with political markets and in that setting they know the economic implications of their decisions
- Should have detailed description of scenarios (avoiding information bias)
- Must contain reminders of resulted budget reduction
- Must contain reminders of the substitutes for the "commodity" in question
- Must include follow-up questions (by asking "what if" any lower or higher value—payment—than the previously expressed, offering opportunities for the respondents to revise their amounts after additional information is provided (Mitchell and Carson 1989: Chap. 4).

5.4.3 Justification and Applications of Environmental Economic Valuation

Several relevant situations are commonly faced involving environmental decision making, which justify the application of environmental economic valuation:

- Comparative economic analysis between short term actions of natural resources exploitation and the long term benefits of conservation

- Project and policies evaluation for the allocation of economic and financial resources
- Establishment and management of protected areas
- Determination of economic liabilities for natural resources damages or degradation
- Compensation for land use regulation for environmental services protection
- Environmental impacts valuation for its integration in economic analysis
- Modification of the national accounting system to reflect the natural capital
- Determination of the influence and contribution of environmental services to local, regional or national economies
- Information and training at all levels to internalize the economic values in the decisions of individuals and institutions.

Among the possible operative instruments that can provide information regarding environmental and economic decision making, are the following:

- Integration of values in cost—benefit analysis
- Economic resources allocation or potential economic-productive use
- Decisions in legal proceedings
- Agreements between intervening parties
- Environmental impact assessment and cost—benefit analysis
- Integration of natural capital in the estimation of GDP
- Information and training programs on the values of environmental services.

5.5 Scenarios for Economic Evaluation of Water Sources Protection

In order to determine the economic return or feasibility of the investments for the protection of water sources for the Metropolitan District of Quito, Ecuador, the corresponding scenarios have to be constructed considering the watersheds characterization and current trends of land use and cover. Furthermore, the source water's quality and quantity, as well as the watersheds management plans, and the current and expected actions and financing, are also considered. In the framework of the territorial system of the Metropolitan District of Quito (MDQ) and particularly of the ecological-territorial subsystem, the land use and cover, and the water quality and quantity on the catchment areas, have a relevant influence interrelated with elements of the socioeconomic, spatial and administrative sub-systems. With the purpose to identify current trends of land use, the situation of the abovementioned elements has been analyzed, taking into account the referential cases of population dynamics, land use and cover, and the water quality and quantity. In the graphs on Fig. 5.7 is possible to observe the population projection and the supply-demand of drinking water in the Metropolitan District of Quito, which reflects the increasing pressure on the use of water resources.

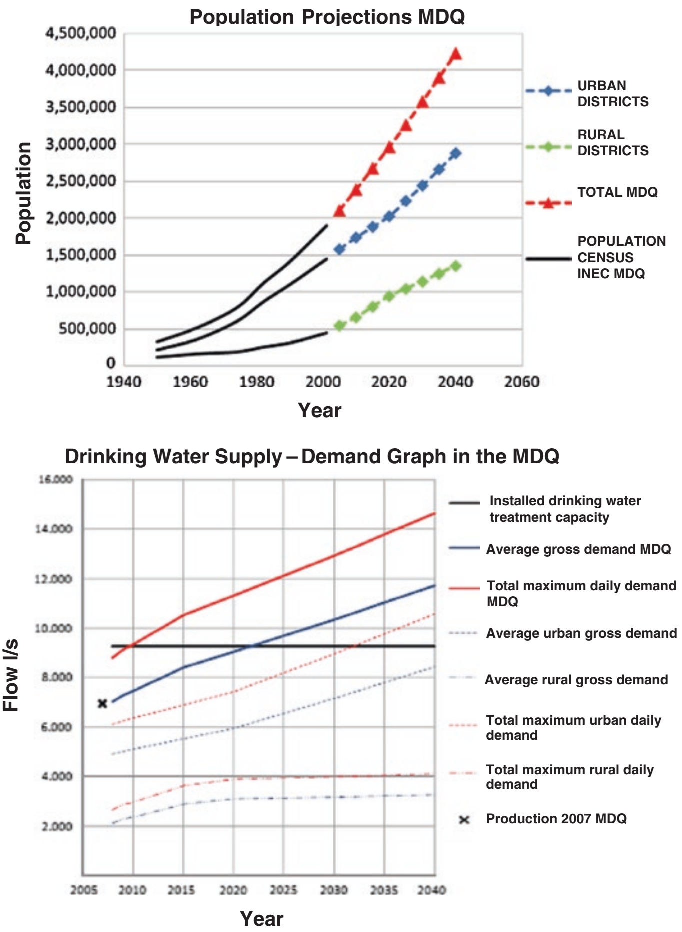

Fig. 5.7 Population projections and water supply-demand in the city of Quito (Drinking water and sewage master plan update. Hazen and Sawyer/EPMAPS-Q 2010)

5.5.1 Watersheds Characterization[1]

The main actions related to the environment that should accompany the processes linked to the watersheds behavior, must be centered fundamentally on measures that allow the planning of sustainable use of watershed environmental services based on the knowledge of its current situation and the pretended future scenario (HYTSA/EMAAPQ 2010). Since the scope of influence of the Water and

[1] 1 ha = 2.47 acres
1,000 m = 3,280 feet
1 mile = 1.61 km
1 km^2 = 0.386 square miles.

Sanitation Company of the City of Quito (EPMAPS[2]), involves an important number of catchment areas from which water is used for the drinking water systems, the objective for a sustainable management of all this territory aims to account with Integrated Management Plans (IMP) for all the management units involved. Besides paying attention to the singularities of each unit, they should be developed based on common and consistent approaches and be implemented following rationality criteria. The drinking water systems currently in operation as well as planned projects involve a number of catchment areas with a surface of 1,720 km^2 (664 square miles), including the planned Eastern Rivers Project with watersheds area of 528.8 km^2. In the indicated analysis a total of 28 watersheds were selected involving almost the totality of catchment areas of surface water that feeds the drinking water systems in operation and planned for the medium term. In Fig. 5.8 the source watersheds of water supply systems for the city of Quito are displayed.

For the watersheds characterization some parameters were considered, as the land cover, land use, mean annual rainfall, mean annual production, mean annual specific production, social conflict level, conservation status, jurisdictional situation, land tenure, use of the resource in or out of the watershed, dominant risk level. A qualitative classification was carried out based in ranges, which has been defined as Environmental Aptitude (Resilience) of the watershed, determined based on the number of parameters that satisfy each condition, and qualified as High, High-Medium, Medium and Low, being this scale proportional to the Resilience of the watershed environmental system. Based on this criteria it is possible to appreciate a high percentage of the selected watersheds presenting a Resilience between High and High/Medium, reaching about 61 % of the watersheds analyzed, while a 14 % show Medium values and near 25 % present a Low Environmental Aptitude.

Although there is a high number of expected interventions on the total number of watersheds (197 interventions), none show a high concentration of expected or necessary interventions in any single watershed. The identified number of interventions according to potential scenarios is between 4 and 11 for each watershed. Out of the 197 total interventions, 104 correspond to non-structural measures, including actions on customs of use, inadequate agricultural practices, land use and others. While the remaining 93 interventions consist of structural measures like erosion control, reforestation and re-vegetation (soil preservation and run off retention).

In order to design Watershed Management Plans and to proceed with the water resource economic valuation, a new selection of watersheds was made taking into account the significance of the total flow produced. With this approach, 6 out of the 28 watersheds are main watersheds producing about 95 % of the total flow consumption by the Metropolitan District of Quito, as detailed in Tables 5.1 and 5.2. The Eastern Rivers Project is in the design phase.

[2] Former EMAAP-Q, is now EPMAPS since 2010.

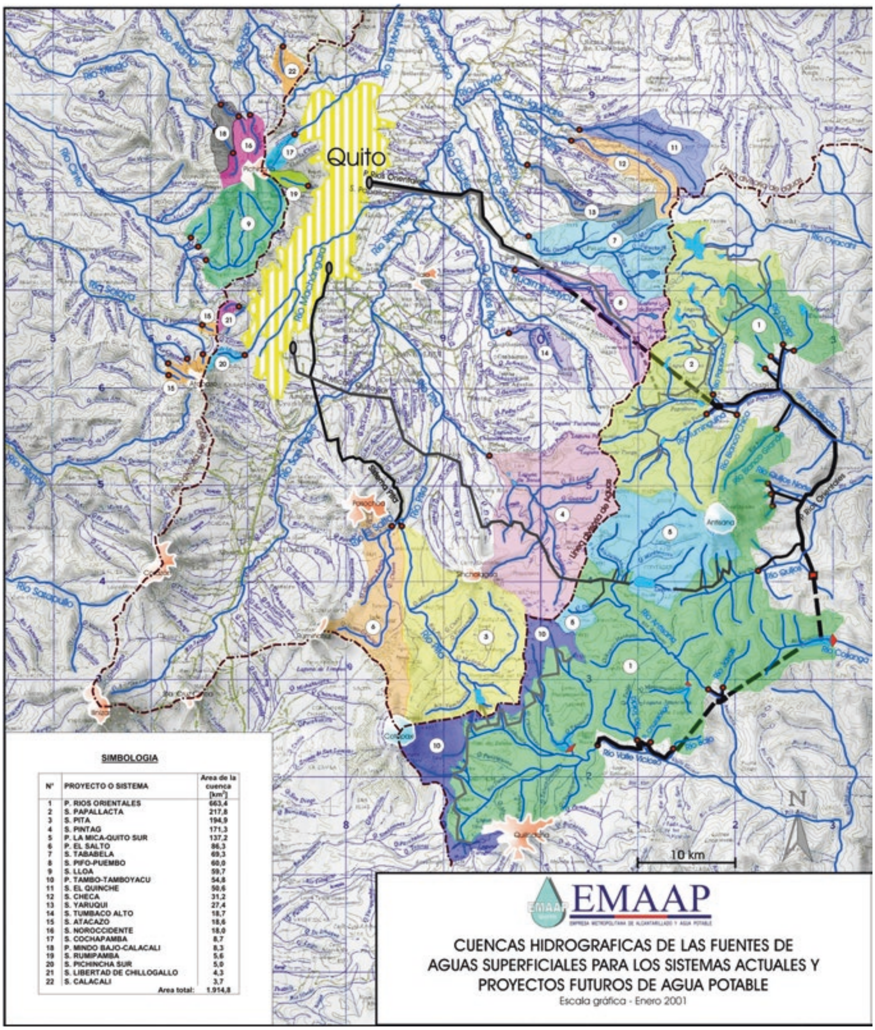

Fig. 5.8 Source watersheds of water supply systems for the city of Quito (Hazen and Sawyer/EPMAPS 2010)

On the terrain map of Fig. 5.9 are displayed the schemes of the main watersheds for the city of Quito, as well as the corresponding main water supply systems. The populated areas appear in darker tone and the developing areas in lighter tone.

The protected areas where the watersheds of the water supply systems of the city of Quito are partly located are displayed on the map of Fig. 5.10, and described in Table 5.3.

Table 5.1 Watershed areas and contribution to total drinking water supply (HYTSA/EMAAP-Q 2010)

	Main water systems/watersheds	Total flow (l/s)
1	PAPALLACTA	2,800.00
2	PITA	2,400.00
3	MICA	1,500.00
4	CENTRO-OCCIDENTE	800.00
5	NOROCCIDENTE	400.00
6	SISTEMAS MENORES - PALUGUILLO	180.00
	Total	8,080.00

Watersheds	Area (km^2)	%	Total flow (l/s)	%
Main watersheds (6)	908.4	53	8,080	95
Eastern rivers project	528.8	31	–	–
Others	282.8	16	420	5
Total	1,720.0	100	8,500	100

Table 5.2 Main watersheds characterization (HYTSA/EMAAP-Q 2010)

		Parameters					
	Sub-watershed	Area (km^2)	Mean annual rainfall (mm)	Mean annual produc-tion (lt/seg)	Mean annual specific produc-tion (lt/seg/ km^2)	Environ-mental resilience	Total flow (l/s)
1	PAPALLACTA FASE1	217.80	1,307.00	727.86	3.34	H-M	2,800.00
	OPTIMIZACIÓN PAPALLACTA					H	
2	PITA	194.90	1,292.00	1,915.82	9.83	H	2,400.00
3	LA MICA – QUITO SUR + IJ	137.20	887.30	170.97	1.25	H-M	1,500.00
4	ATACAZO + ATACAZO BAJO	18.60	1,403.00	10.03	0.54	H	800.00
	PICHINCHA SUR	5.00		97.29	19.46	H	
	LLOA	59.70	992.80	115.13	1.93	L	
5	NOROCCIDENTE	18.00		28.86	1.60	L	400.00
6	TABABELA	69.30		12.55	0.18	M	180.00
	PIFO—PUEMBO	60.00		30.07	0.50	L	
	EL QUINCHE	50.60	552.40			H	
	CHECA	31.20				L	
	YARUQI	27.40	612.20	7.72	0.28	M	
	TUMBACO ALTO	18.70		12.84	0.69	L	
	Total area	908.40				Total flow	8,080.00
	High	0 > 20.5	>1,000	>240	>6		
	Medium	20.5–41.0	999–500	81–240	3–6		
	Low	>41.0	<500	0–80	0–3		

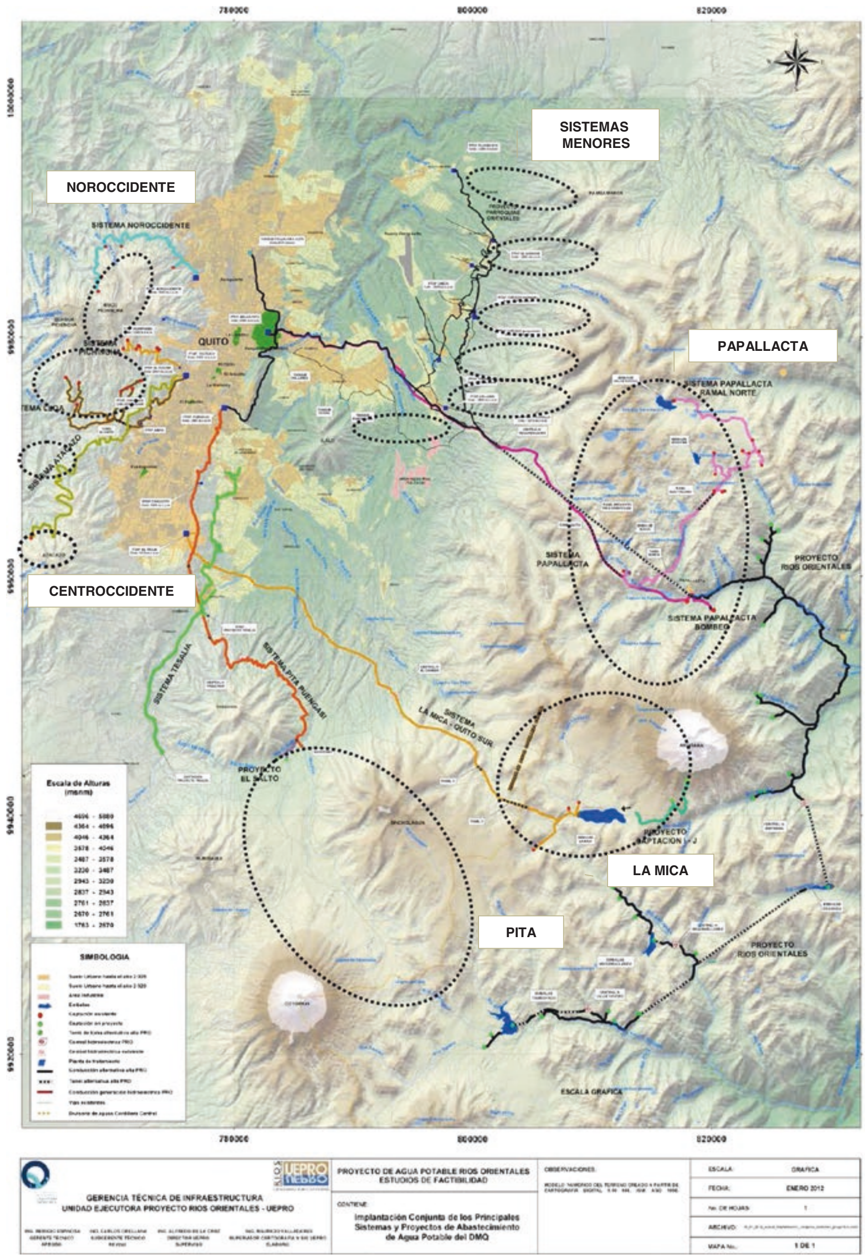

Fig. 5.9 Water supply systems and watersheds schemes of the city of Quito (EPMAPS 2012)

The recently acquired lands correspond to La Mica and Pita Water Supply Systems, with approximately 7,000 ha on each one of the watersheds.

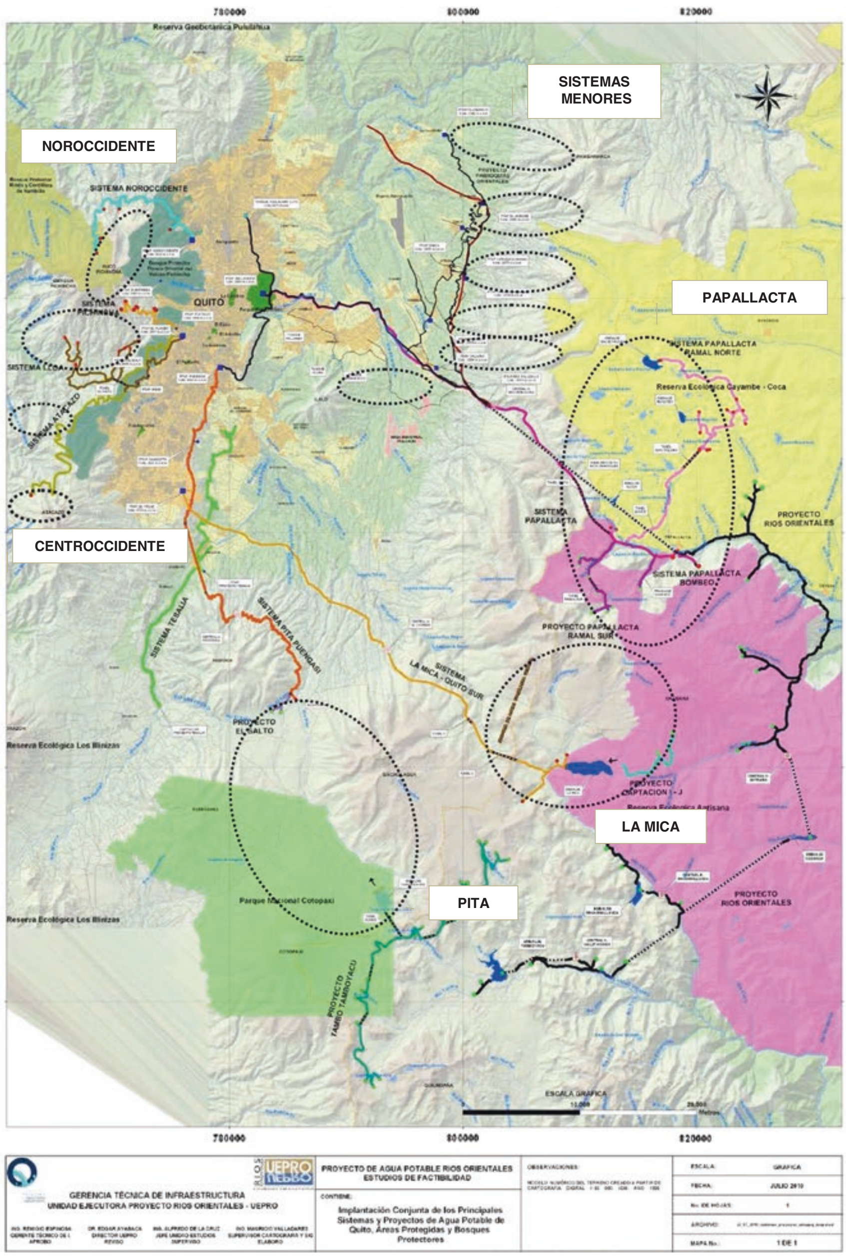

Fig. 5.10 Water supply systems of the city of Quito and protected areas (Hazen and Sawyer/EPMAPS 2010)

Table 5.3 Protected areas affecting water supply systems

Water supply systems	Protected areas partly on the watersheds
Papallacta	Cayambe—Coca National Park and Antisana Ecological Reserve
La Mica	Antisana Ecological Reserve
Pita	Cotopaxi National Park
Noroccidente	Mindo—Nambillo Protecting Forest and Pichincha Volcano's Eastern Slopes Protecting Forest
Centroccidente	–
Sistemas Menores (Paluguillo)	Cayambe—Coca National Park (minor area)

5.5.2 *Current Actions and Financing*

Since the year 2000, the Quito City Ordinance (By Law) related to the protection of catchment areas—contributions and incentives, based on the decreasing availability of the water resource due to pollution, land use changes and deforestation processes, authorized the creation of the trust fund for the conservation and maintenance of the watersheds for the city's water supply. The Environmental Fund for the Protection of the Watersheds and Water Resources (FONAG) involves EPMAPS, The Nature Conservancy, The Power Company, Cervecería Andina and the Swiss Cooperation in Ecuador.

The environmental Ordinance of 2007 (Art. II.383.7. Contribution for the Protection of Water Sources) ratified the contribution of 1 % of the monies collected monthly by EPMAPS to FONAG. FONAG is the entity that will be in charge of investing in programs and projects for the protection, conservation, recovery and revaluation of watersheds and water resources that supply to the Metropolitan District of Quito. This contribution will increase 0.25 % annually, until it reaches 2 %, an amount that will be maintained and will contribute to the permanent search of water supply in adequate conditions for its consumption. These contribution values (percentages) for the protection of water sources, do not account for any technical, environmental or socioeconomic justification. In Table 5.4 are shown the transfers from EPMAPS to FONAG and the Trust Fund yields. The values of 2009–2011 are projected.

5.5.3 *Design and Implementation of Watershed Management Plans 2006—2012–2016*

In the year 2006 the Watersheds Management Plans for the drinking water systems Papallacta and La Mica were formulated, and partly implemented to date, including the acquisition of 7,000 ha in each system's watersheds. Between 2011 and 2012 the management plans were designed for the catchment areas of the water

Table 5.4 Transfers from EPMAPS to FONAG and trust fund yields (FONAG 2013)

Transfers from EPMAPS to trust fund FONAG		
Year	% Increased	EPMAPS (US$)
2004	1.00	611,836
2005	1.00	492,637
2006	1.00	790,588
2007	1.00	752,609
2008	1.25	1,005,850
2009	1.50	1,188,000
2010	1.75	1,407,000
2011	2.00	1,632,000
2012		
Total		7,880,520

FONAG—trust fund general yields	
Year	Yields (US$)
2004	133,774
2005	221,430
2006	338,637
2007	316,572
2008	496,481
2009	640,000
2010	750,000
2011	902,102
2012	950,000
Total	4,748,996

systems Pita, Centrooccidente, Noroccidente and Sistemas Menores (Paluguillo), as well as the management plans of the reservoirs La Mica, Salve Faccha, Sucus and Mogotes. On these management plans for the main watersheds, were identified ongoing processes of land cover degradation of the water supply catchment areas and the natural ecosystems for water regulation, lack of land use regulations, insufficient conservation and inadequate management of the natural setting, especially of the water resource and the structural components of some of the drinking water systems. These issues, as well as the lack of stakeholders' participation in sustainable management, have to be addressed in order to assure the lifespan of the water supply systems for the city of Quito.

General programs, processes and actions were considered in all the management plans, as well as some specific measures depending on particular situations of some of the watersheds:

General Common Management Programs

- Protection and restoration of the watersheds' ecosystems
- Environmental, meteorological, hydrologic, and water quality and demand monitoring

- Environmental control and water quality surveillance
- Training, dissemination and environmental education
- Institutional coordination and strengthening.

Specific Management Programs

- Support to local community development
- Improvement of water use systems and their management
- Information generation on water resources and water supply systems.

The costs or investments assigned for the different programs do not vary greatly from each other, except for the planned land acquisitions that are part of the programs for the protection and restoration of the watersheds' ecosystems.

5.5.4 Scenarios Construction According to Protection Requirements

'Scenarios are stories about the future, but their purpose is making the best decisions in the present'. Their construction is like doing an exploratory journey that can change the way we see and understand the world (Shell International 2008).

The scenarios deal with the spaces unaccounted with information, challenging suppositions, expanding the visions and combining information from different disciplines. Many key questions should be made: How to describe the current situation? Which are the crucial issues from the past? Which are the lessons?

Once a common understanding of the scenarios is reached, there is a base to think about the implications of a future strategy. The scenarios form the base on which it is possible to deepen our understanding and be conscious of the limitations of our current thinking. Just as the world does not remain static, neither do the scenarios.

According to the analysis of the issues regarding the situation of the catchment areas of water supply for the MDQ, the planned programs and actions in the corresponding management plans represent the variables for the construction of scenarios.

The objective variables considered to define the scenarios, are:

- The amount of funds assigned for land purchases
- The greater or lesser funds to finance the execution of the programs and actions.

Besides the variables for the construction of scenarios, different management options have to be taken into account, as described in the Table 5.5.

5.5.5 Scenarios Costs/Investments

Related to the costs or investments required for different management categories, three scenarios have been defined:

Table 5.5 General watershed management options

General watershed management options		
Ideal	Feasible	Basic
Protection category for catchments areas Water resource preserved for the supply to the city of Quito Significant area of purchased land in order to adequately protect and control its use Budgets of watersheds management plans, adjusted with +20 % to ensure the implementation of planned actions	Natural resources preserved by means of sustainable productive alternatives The area of purchased land allows an acceptable protection and control of its use	Inexistence of an agreed program for natural resources conservation The limited area of purchased land does not allow an adequate protection and control of its use Budgets of watersheds management plans, adjusted with −20 % for unexpected financial constrains

- Ideal
- Feasible
- Basic

1. Ideal scenario					
Management plans budgets 2013—2016					
Systems	Number of years	Total optimum (+20 %) (US$)	Land acquisition (ha)	Land acquisition (US$)	Mean annual budget 2013–2016 (US$)
Papallacta	4	1,997,136			499,284
Pita	4	5,048,628	14,000	20,000,000	6,262,157
Mica—Quito Sur	4	2,715,043	8,000	8,000,000	2,678,761
Centrooccidente	4	1,400,220	2,000	4,000,000	1,350,055
Noroccidente	4	600,000	1,500	4,000,000	1,150,000
Sistemas Menores	4	300,000			75,000
La Mica Reservoir	4	2,186,190			546,548
Salve Faccha, Sucus, Mogotes Reservoirs	4	1,543,020			385,755
Operative costs EPMAPS					345,000
FONAG/Others					4,725,451
Total		15,790,237			**18,018,011**

2. Feasible scenario					
Management plans/budgets 2013–2016					
Systems	No. years	Total feasible (US$)	Land acquisition (ha)	Land acquisition (US$)	Mean annual budget 2013–2016 (US$)
Papallacta	4	1,664,280			416,070
Pita	4	4,207,190	8,000	10,000,000	3,551,798
Mica—Quito Sur	4	2,262,536	5,000	5,000,000	1,815,634
Centrooccidente	4	1,166,850			291,713
Noroccidente	4	500,000			125,000
Sistemas Menores	4	250,000			62,500
La Mica Reservoir	4	1,821,825			455,456
Salve Faccha, Sucus, Mogotes Reservoirs	4	1,285,850			321,463
Operative costs EPMAPS					300,000
FONAG/Others					4,109,088
Total		13,158,531			11,448,721

3. Basic minimum scenario					
Management plans budgets 2013–2016					
Systems	Number of years	Total basic (-20 %) (US$)	Land acquisition (ha)	Land acquisition (US$)	Mean annual budget 2013–2016 (US$)
Papallacta	4	1,331,424			332,856
Pita	4	3,365,752	3,000	5,000,000	2,091,438
Mica—Quito Sur	4	1,810,029	2,000	2,000,000	952,507
Centrooccidente	4	933,480			233,370
Noroccidente	4	400,000			100,000
Sistemas Menores	4	200,000			50,000
La Mica Reservoir	4	1,457,460			364,365
Salve Faccha, Sucus, Mogotes Reservoirs	4	1,028,680			257,170
Operative costs EPMAPS					240,000
FONAG/Others					3,287,270
Total		10,526,825			7,908,977

5.5.6 Valuation of Source Water and Scenarios' Benefits

The costs and investments necessary to adequately and sustainably manage the catchment areas are not complex to determine since most of the planned actions have a market price. However, the benefits of assuring the required water quality and quantity are difficult to calculate since the water in its natural state, as a good of public use,[3] does not have a price.

As described earlier in this paper, an accepted methodology and currently of common application to determine the benefits of common resources like source water, is to estimate the Willingness-to-Pay (WTP) for optimally or ideally improving or avoiding degradation trends of its quality and quantity, by means of the Contingent Valuation Method and the corresponding survey. This work was carried out in the Metropolitan District of Quito (MDQ), in the framework of the Decontamination Plan of the Rivers of the City of Quito (Fitchner/EMAAP-Q), in the year 2011.

The survey was applied to a sample of 1,255 respondents that corresponded to the universe of the MDQ population, and complied with the requirements also

[3] The Art. 318 of the Ecuadorian Constitution, establishes that " … water is strategic national patrimony of public use …", and in Art. 74 "Environmental services will not be susceptible of appropriation; their production, supply, use and utilization will be regulated by the State."

Table 5.6 Benefit—cost analysis for watersheds and reservoirs management plans

Year	Population	r	Customers	Benefits (WTP) (US$)	Costs (US$)	O&M (US$)	Total Costs (US$)	B-C (IRR)
2013	2,362,297		485,071		18,018,011	1,801,801	19,819,812	-19,819,812
2014	2,404,818		493,803		18,018,011	1,801,801	19,819,812	-19,819,812
2015	2,448,105		502,691		18,018,011	1,801,801	19,819,812	-19,819,812
2016	2,492,171		511,739		18,018,011	1,801,801	19,819,812	-19,819,812
2017	2,537,030		520,951	54,387,253		3,603,602	3,603,602	50,783,651
2018	2,582,696		530,328	55,366,223		3,603,602	3,603,602	51,762,621
2019	2,629,185		539,874	56,362,816		3,603,602	3,603,602	52,759,213
2020	2,676,510	0.0145	549,591	57,377,346		3,603,602	3,603,602	53,773,744
2021	2,715,320		557,561	58,209,318		3,603,602	3,603,602	54,605,716
2022	2,754,692		565,645	59,053,353		3,603,602	3,603,602	55,449,751
2023	2,794,635		573,847	59,909,626		3,603,602	3,603,602	56,306,024
2024	2,835,157		582,168	60,778,316		3,603,602	3,603,602	57,174,714
2025	2,876,267		590,609	61,659,602		3,603,602	3,603,602	58,055,999
2026	2,917,973		599,173	62,553,666		3,603,602	3,603,602	58,950,064
2027	2,960,283		607,861	63,460,694		3,603,602	3,603,602	59,857,092
2028	3,003,207		616,675	64,380,874		3,603,602	3,603,602	60,777,272
2029	3,046,754		625,617	65,314,397		3,603,602	3,603,602	61,710,795
2030	3,090,932	0.0115	634,688	66,261,455		3,603,602	3,603,602	62,657,853
2031	3,126,478		641,987	67,023,462		3,603,602	3,603,602	63,419,860
2032	3,162,432		649,370	67,794,232		3,603,602	3,603,602	64,190,630
2033	3,198,800		656,838	68,573,866		3,603,602	3,603,602	64,970,264
2034	3,235,586		664,391	69,362,465		3,603,602	3,603,602	65,758,863
2035	3,272,795		672,032	70,160,133		3,603,602	3,603,602	66,556,531
2036	3,310,433		679,760	70,966,975		3,603,602	3,603,602	67,363,373
2037	3,348,503		687,578	71,783,095		3,603,602	3,603,602	68,179,493
2038	3,387,010		695,485	72,608,601		3,603,602	3,603,602	69,004,999
2039	3,425,961		703,483	73,443,600		3,603,602	3,603,602	69,839,998
2040	3,465,360		711,573	74,288,201		3,603,602	3,603,602	70,684,599
			NPV 12 %	470,318,188		NPV 12 %	78,026,976	39 %

detailed earlier in this paper. The contingent valuation study included questions as covariates, regarding environmental quality perceptions, respondents' income level, payment vehicle, and current Dollar amounts of the drinking water and sewage bills, among others. The respective risk and sensitivity analysis were carried out as well.

The results of the Willingness-to-Pay model for improving or avoiding degradation trends of source water quality and quantity, produced a value of US$ 8.70/customer/month, which is used in the Benefit—Cost analysis that is summarized in Table 5.6.

5.6 Benefit—Cost Analysis

The period considered for the Benefit—Cost Analysis for the watersheds and reservoirs management plans goes from 2013 to 2040.

The population projection is calculated with decreasing annual growth rate from 1.80 to 1.45 % and 1.15 %, in every decade of the analysis period. The number of customers corresponds to the population divided by 4.87 (average number of members per household).

The costs correspond to the mean annual budget established in the management plans from 2013 to 2016, and the operation and maintenance (O&M) costs are estimated as 10 % of the costs.

The estimated benefits by means of the application of the Contingent Valuation Method for the determination of the Willingness-to-Pay, represent the benefits of an ideal protection and conservation of water resources. This is why situations of non ideal protection and conservation are not considered in the benefit—cost analysis, which was carried out with the costs of the Ideal Management Scenario.

The Net Present Value (NPV) of benefits is US$ 470,318,188, and for the costs, the NPV is US$ 78,026, 976. The Internal Rate of Return (IRR) for the scenario analyzed is 39 %, which demonstrates the economic feasibility of the corresponding investments. In Table 5.6 are shown the calculations.

This will allow its dissemination and training at all levels in order to internalize the environmental economic values on individual and institutional decision making and to improve the Perception of Value (Satisfaction/Price Relation) Index for the provision of services by EPMAPS, and contribute to the reduction of consumption and the non accountable water index.

5.7 Conclusions

Decision making on how to best use the natural resources and formulate environmentally sustainable policies, must integrate the total value society assigns to goods and services, whether they are part of the market or if they are non-use values. Only by integrating the total values in the benefits and costs estimation, economic analysis would be an appropriate appraisal and decision tool.

Scientific and methodological principles and guidelines have to be closely followed when valuing environmental services and carrying out economic evaluations of proposed alternative states. In order to properly assess policy options one must avoid undermining important scientific advances in these fields, and unintentionally misleading decision makers.

Since water as a natural resource and a good of public use doesn't have a production market value, it is fundamental to estimate its non-use values and to demonstrate the economic feasibility of the required investments for the protection of the availability, quality and flow regulation of water sources, taking into account the costs involved and the total economic value or benefits calculated by means of environmental economic valuation instruments as the Contingent Valuation Method. This will allow its dissemination and training at all levels in order to internalize the environmental economic values on individual and institutional decision making.

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Part II
Global, Trans-boundary and International Dimensions

Chapter 6
Is Water Really a Scarce Resource? Initiating Entrepreneurship for Global Clean Water Supply

Implications of a Global Economic Policy on Water Security and Entrepreneurial Technology Strategy

André Presse

Abstract It is a widely spread assertion that water is a scarce resource. Most experts agree that for many inhabitants of less developed countries it is difficult to obtain a sufficient amount of clean water. We add to this argument by saying that it is the case not so much because there is not sufficient drinkable water on this planet but rather because not all consumers have sufficient purchasing power. This chapter suggests to use the revenue from scarce resource rents in order to enable even the poorest to have access to clean water. An integrated global economic policy systematically ensuring sufficient financial means for everyone, including the poor, for purchasing at least the drinkable water to survive, and incentivizing global entrepreneurship as well the application of the latest, environmentally-friendly technology in this field.

Keywords Water resources · Climate change conflict resolution · Global economic policy · Technology management · Innovative entrepreneurship

6.1 Introduction

"There is no limit to how many times water can be reused" says Biswas (2010), hydrologist and consultant to the United Nations. The availability of clean drinking water therefore is only a matter of desalination and purification. Why then is one of the most commonly held notions about water as a resource that it is extremely scarce? Some go so far to speak of "Wars over Water" to come in the 21st century. Wealthy nations are

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_6

likely to have access to sufficient drinkable water also in the future. Less fortunate citizens of poorer nations on the other hand will face even harder times than today securing the water they need to survive. But is this notion really true? Is it a “divine law”, the actual absence of drinking water that is causing the shortage? Or is it made by man, responsible for a system that makes people suffer from a lack of access to clean water caused by a lack of purchasing power? This chapter elaborates on the basic fact that there is enough drinking water on this planet for everyone, because water is not used-up by its consumers but remains part of the greater circle and can be made available through desalination and purification. It is not even always necessary to desalinate and purify it. Clean water is there already and all that is needed is to provide the purchasing power to those in need for it. In this chapter an economic model is developed, based on scarcity rents, to secure the purchasing power needed for water. Implementing this model ensures that in a globalized world, currently established mainly in the shape of a global economy and increasingly a global knowledge society (e.g. through Internet, cultural exchange etc.), the dealing with a global common good is organized on a global scale. Other areas calling for global legal arrangements are financial markets, security, taxation and natural resources. The problems currently arising in these fields help us understand that national legal arrangements are not fit to solve these problems and that we increasingly need global legal arrangements. This chapter outlines a global legal arrangement for dealing with emissions globally in a way that ensures for a sufficient water supply by granting the purchasing power necessary.

Former US-president Wilson (1918) (in office 1913–1921) proposed a system of *self-determination of peoples*, i.e. of ‘nation states respecting each other and dealing with each other on equal terms’. Wilsons system was very influential in the 20th century in shaping the world as we know it. The model proposed in this chapter enforces a system of *self-determination of the people,* of ‘individuals respecting each other and dealing with each other on equal terms’. At the beginning of the 21st century mankind is confronted with challenges arising from the nation-based. In fact, at the core of some of the most threatening problems is the concept of the national state, which this chapter argues is inappropriate for dealing with some of the problems we currently face. This chapter suggests gradually developing the approach of the *self-determination of the peoples* towards to the *self-determination of the people*, i.e. *of the individual human being*. That people can meet and act on equal terms requires them not to depend on each other, otherwise individuals can always be forced and undermined by others. Providing the minimum funds needed for survival contributes to individual independence. Applying a global emissions control scheme that redistributes the scarcity rent from emissions as a global common good to the people directly rather than to national states grants the funds for purchasing clean water and *ignites the entrepreneurial initiative required to make clean water available*.

6.2 Problem Statement: Finding the Right Question

We do not *consume* water in the way that we use it up. Water is only *used* and remains part of a global circulation. For instance, when we drink water, the body keeps only a very small portion of it, and even that small portion is lost in transpiration. If our body would not sooner or later dispose of all the water it takes in, we would soon acquire overweight beyond healthy conditions. So, in other words, if we are not actually destroying the water we use, what causes the notion that there is not enough drinking water on this planet to satisfy the thirst of all its inhabitants?

Citizens in wealthy nations find it less difficult, due to a functioning infrastructure, to have access to the water they need on a daily basis. This planet holds enough drinking water to satisfy the thirst of everybody. We typically raise the question: "How can we make water available to those who are most in need?" In fact, the answer is already given by economically leading nations: make sure that your inhabitants dispose of sufficient financial means to afford it. Only then both public infrastructure and private entrepreneurial initiative as well as technological innovations are created to make clean water available to them.

The subsequent question is: "How much money is needed to make water, at least the minimal volumes of drinkable water needed on a daily basis, available to everybody?" That of course depends on the price for water. So a policy-model must be found that links an increase in prices to an increase in income. A commons-based approach is chosen that redistributes per capita the revenues increased through an increase in prices. Hardin (2009) has suggested capping emissions and sharing emission rights between countries. A commons based approach. Also Nobel Laureate Elinor Ostrom[1] (1964), sees the need for an increased awareness of the common good character of natural resources (Wilson and Eckel 2013). On this basis, we arrive at the question guiding the research in this chapter: "How can a commons-based economic policy help to make that money available?"Arguments are presented and evaluated that this can be achieved by auctioning emission rights globally and redistributing revenues to the *individual person*.

6.3 Literature Review

The founder of the economic sciences, Smith, differentiated three production factors labor, capital and land. Land, in today's terms, can be substituted by "natural resources", or, on more general terms, as a common. Most professional economists are trained dealing primarily with labor and capital, featuring as L and C in the generally accepted equations in the economic sciences globally. The third production factor can hardly be found in any of these equations. Stiglitz (2014) argues that a large fraction of income inequality is caused by extreme inequality in the distribution of rents associated with land and other natural resources. It is fair to say that land receives its value only through the impact of capital and labor and can therefore be treated as a function of the other two. However, it must not be ignored that labor and capital can be augmented, increased and is actually created by man, land can and is not. This fundamental difference led Walras (1877), the founder of the general equilibrium theory,

[1] Ostroms dissertation was on "Public Entrepreneurship: A Case Study in Ground Water Basin Management".

to conclude land (natural resources) to be treated separately and as a common good in some kind of public private partnership, i.e. publically owned and privately utilized through long leases, potentially as unlimited as in the case of actual private ownership. There is one major difference between private ownership and private lease of land: in the case of private ownership, the value appreciation (speculative value) goes to the private owner, while in the case of the lease the public benefits from value appreciation. As capitalism is based on meritocracy, those who dispose of land should only benefit from the merits of what they do with it. The benefit of land appreciation due to a general increase of land value in a city or region is the benefit of the public. An anecdotal aspect of this review serves to illustrate the general (mathematical) case made by Walras (1896, 186–194; see also Gaffney and Harrison 2007). Walras developed a mathematical theory, still not translated from the French original, in his Theory on Property (Theorie de la proprieté). To ensure land is used by those who realize the greatest economic benefit rather than those who keep it for speculation, Walras suggested a long lease.[2] The implementation of his theory requires a major paradigm shift (a "game changer", if you want), but with economic crises continually emerging from the real estate sector over centuries, economists may take another look at it.

Walras' basic reasoning that human effort can create labor and capital but that it cannot *create* land led to the idea of long leases. This concept is fully conform to a market economy and applied in some of the most prosperous economic centers like Hong Kong, London and New York. Large areas in the City of London, for instance, are owned by a handful of owners. The City of Westminster, just west of the City of London, is basically owned by the Duke of Westminster. Large areas of Lower Manhattan in New York City are owned by the New York Port Authority, a public body that gained land ownership as it was for centuries in charge of welcoming and temporarily housing immigrants arriving in New York. Centers of the global market economy are established on land used the way Walras suggested it. This chapter applies the lessons learned to an economic model for dealing with emission rights today. We show that this application helps reducing emissions globally, providing a predictable path in the short and long run by setting predictable emissions reduction paths for the industry. At the same time the model grants the financial means to have access to the minimum amount of money required for clean water daily. In this chapter we do not look at the real estate sector but on the implications of Walras' theory for another natural resource: atmosphere.

Eisenbeis (2008), former advisor to the European Union on Energy Affairs, remarks that "mankind has all means at their disposal necessary to solve the climate problem: the knowledge, the resources and the capital. They are just not distributed in a way that a solution emerges." The following model therefore proposes a slightly different distribution that is able to solve the problems at hand: pollution, climate change and extreme poverty as one of the major causes for conflicts and war.

[2] To avoid a traditional misunderstanding: Private homes should be privately held. It is large masses of land and in highly priced lots (with high levels of speculation rather than real use of land) for which long lease is most appropriate. Examples follow later in this chapter.

6.4 The Model

This model proposes an economic policy allocating the resources in a way that resolves these problems (Andres 2001). The model is based on three principles represented by three respective policy levels building on one another: *Sufficiency*, as the first level, ensures that a *maximum amount of emissions is not exceeded*. This level is vital for the overall goal of any climate policy to reduce emissions or at least keep them at bay. *Efficiency*, as the second level, secures an economic use; i.e. emissions have a price as a systematic incentive to avoid them. Level 2 basically *puts a price tag to polluting the atmosphere*. *Equivalence*, as the third and last level, makes sure that *revenues from level* two *go to the* "*owners*" *of the atmosphere* and that the price tag does not lead to situations where people cannot afford to pay for their minimum requirements. Let's have a closer look at these three levels.

6.4.1 Level 1: Sufficiency

The Intergovernmental Panel on Climate Change (IPCC) provides a general framework for understanding the human impact on climate change. Even though the numbers vary, IPCC reports support the general understanding that the Earth's atmosphere can absorb about 20 gigatonnes (Gt) carbon dioxide (CO_2) annually (IPCC 2007, 48–50).

It is widely accepted that at least part of the climate change is anthropogenic, i.e. due to human impact. If our emissions exceed the maximum allowed volume for a number of years, the impact becomes stronger. A large fraction of the human impact on climate change can be traced back to our emission of CO_2. Among the greatest causes for those emissions is the combustion of oil, coal and gas.

For each ton of oil, coal and gas burned, the amount of emissions incurred is known. The precise figure depends on the actual chemical composition, on very general terms we can say that for each ton of oil and coal burned roughly three tons of CO_2 are emitted, for each ton of gas about 2.5 tons of CO_2. This allows for an upstream capture of emissions (Rahmeyer 2004, 8) following for the logic that *whenever someone is introducing oil*, *coal and gas into the economic cycle*, *he or she must prove that he has purchased the equivalent amount of emission rights* (Eisenbeiss 2007).

This approach realizes an input-orientation allowing for an effective reduction of emissions. Rather than trying to monitor, trace, track and reduce emissions at virtually billions of emission points, the *major cause for emissions is addressed upfront*. Quite naturally, with such a policy, a number of questions arise, such as how governments in the emitting (and imitting) nations can be brought to the table. For some answers to this and other questions please refer to the section "Further Questions" below.

Shocks can be avoided by applying this model, as it installs a predictable reduction path. Let us assume current emissions are 50 Gt per year. Applying the first stage of the model allows embarking on a reduction path starting at, for instance, 50 Gt in year one and then reducing the amount of emissions auctioned (see level 2) at a certain rate or amount. If this amount is one Gt annually, this results in a predictable reduction path of 49 Gt in year two, 48 Gt in year three etc. This allows corporations to calculate the expected costs in advance. In turn, they can embark on a path replacing CO_2-intense technology by less CO_2-consuming technology gradually over several years and write off old machinery. After a given amount of time—in this example 30 years—we arrive at the suggested upper limit put of 20 Gt forth by the IPCC.

Such an upper limit may appear difficult to maintain and implement as a global policy. As difficult as it may seem, there are already similar policies in effect. One example are fishing quotas, where several nations agree to maintain an upper limit of certain kinds of fish being brought out of global oceans. There are certainly still shortfalls in these agreements but the general framework is obeyed demonstrating that intergovernmental policies are effective if participants agree and fear the consequences of breaching it. The consequence of breaching climate change preventing agreements is a worsening environmental condition, which policy makers can accept until the conditions become bad enough to force them to take action.

6.4.2 Level 2: Efficiency

Economic theory suggests that a price reflects the actual result of supply and demand. Currently, emissions prices vary between nations according to policy differences. Emission in the past were and are still assigned nationally, and then further distributed by national governments through regular sale or auction or just "given" to corporations. This gives industry the power to, in some cases, force national governments to grant emission rights for free by threatening to otherwise relocate production and jobs elsewhere.

The current policy leads to global inefficiencies that can be avoided by establishing a globally unified emission price. The suggested price building mechanism is **auctioning the emission rights globally**. This global amount ("upper bound") must be determined by environmental scientists (see level 1), supposedly by panels like the IPCC. The obvious body for organizing a global auctioning process is the United Nations (UN). If the UN establishes a fund for conducting the global auctioning, it can initiate a global process for emission rights and pool the funds.

Who will be the typical bidder for those emission rights? Assuming the upstream regime suggested in level 1, typical bidders would not so much be manufacturers or heavy industry emitting CO_2. They are today "using" fossil fuels and "cause" the emissions. The upstream capture mentioned above puts the burden rather on the companies that exploit, extract and process the fossil fuels and introduce it into the economic cycle, i.e. global oil corporations and a number of corporations in Gulf States, as they are the locus the fossil fuels enter the economic cycle. Even though there is a number of corporations doing that, the number is significantly smaller than the millions of emitters. So it will be easier to monitor that the respective corporations are in compliance with global policy.

As a consequence, every corporation downstream can acquire fossil fuels in good faith only if the vendor proves that he has purchased the amount of emission certificates necessary to offset the emissions occurring when fuels are burned. Practically this is done by furnishing the emissions certificate as a documented proof of purchase as a copy downstream to all stages in the production chain.[3]

Emission rights currently are still partially given away for free (see Presse 2009, 3–12) and it is difficult to make educated assumptions on future emission prices. On very general terms, the price depends on the amount of emissions auctioned and on the sales price obtained, and that is of course highly dependent on the general economic situation. When this chapter was completed, the emission price was around 5 EUR per ton. Two years before it was around 15 EUR. Lower prices can be attributed to the fact that there is still no effective mechanism in place to enforce compliance with global upper emission limits. To avoid economic shocks the model should initially be applied on a level of emissions "as is". The current amount of total emissions ranges between 40 and 50 Gt (IPCC 2007, 6). The following Fig. 6.1 displays a possible reduction and price path at a given demand as a function of supply, in this case the volume of CO_2 allowed for emissions.

Starting from an allowed emissions volume at or beyond 50 Gt, we assume for this example an emission price at or below 20 EUR/t. Any lower allowed amount of emissions results in an increasing emission price. In the forthcoming years, the allowed amount for auctioning can be reduced, here for demonstrating the principle it is reduced by one Gt per year. As volumes shrink, emission prices increase, and so does the economic incentive for employing technologies that save emissions. Auctioning emission certificates for 50 Gt for a price of 20 EUR per ton is resulting in revenues of 1 trillion EUR. As allowed volumes decrease and prices increase at a given demand, at 40 Gt in this scenario the emissions price is 30 EUR per ton and auctioning revenues are 1.2 trillion EUR. So the amount paid out can remain stable over decades as emission volumes are reduced and with even an increasing global population.

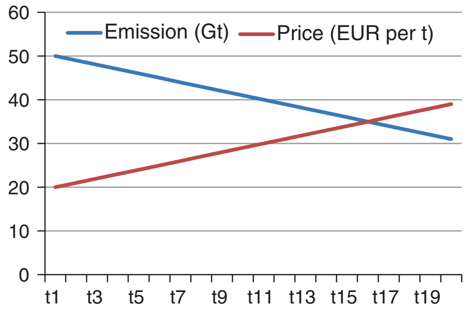
Who will pay for the costs increasing through the price of purchased emission rights? There is an extended scientific debate on incidences, for instance tax incidence (for instance Andel 1998, 110). As far as this chapter is concerned, it suffices to acknowledge that all costs of any production are carried by the consumers. This is the case on a product base, for companies as well as for economies in general.[4] This does not change under the proposed policy.

Having this in mind, the argument is easier to understand why the revenues derived from increased costs through any climate change prevention policy should be redistributed to consumers in order to avoid additional hardship caused by any climate

[3] This is part of the regular procedure already today. Shipping documents comprise a number of different certificates, of which the emission rights certificate will be one.

[4] Temporary exceptions can occur. Products can be cross-subsidized; then their costs are carried by those who pay for other products. If corporations cannot obtain the costs for the products and services they offer, they sooner or later go out of business.

Fig. 6.1 Allowed emissions (in Gt) and emissions price (in EUR per t)



regime. Current regimes lead to increased costs—e.g. electricity bills, insulation for buildings—without compensating those who incur higher costs clearly suffer from a loss of purchasing power. The following section explains why the proposed policy is leading to price incentives for reducing emissions and at the same time yields reimbursements avoiding a loss in purchasing power for the average consumer.

6.4.3 Level 3: Equivalence

So far the model follows the cap and trade-principle of other climate change prevention schemes, except that those do not foresee upstream capture and global auctioning. In addition, this chapter suggests redistributing the proceeds from the auctioning process per capita to the world population (see also Presse 2009). One of the first questions arising is: how high will the revenues from the auctioning process be? This depends on the amount of emission rights auctioned as well as the auction price obtained for the emission certificates (see level 2). It is a challenge to reasonably estimate the amount of revenues generated in the auctioning process. The actual price is subject to and a function of many factors, for instance the future demand for fossil fuels. Eisenbeiss notes that current emission price fluctuations are due to economic cycles. In other words: as oil becomes more expensive due to increased demand, so will emissions prices. If oil or emission rights do not become more expensive, there is less need for increasing reimbursements.

There are at least three major reasons for a per capita-redistribution of the proceeds from the auctioning process: an *economic*, a *political* and something that can be called a *natural reason*. As mentioned above, one reason to give the money "back" to consumers is that they are the ones who pay for it as they pay the entire production costs of any good they purchase, i.e. they 'carry' the costs in the first place. Of course each customer to a different extent, according to individual consumption. Some consume more than average, others less (for a discussion of the implications of that, please see the last section of this chapter). Those who consume more than average financially are net contributors. Those who consume less are financially net benefiters. In short, the consumer is paying for climate change prevention, so the consumer is entitled to be reimbursed for her or his increased costs (average costs). This is the *economic reason* for per capita-redistribution.

A second reason is that international climate negotiations have failed in the past mainly because emerging economies like India and China cannot agree to climate regimes forcing them to reduce emissions, as they have relatively low emissions per capita compared to economically more developed nations. At the same time, affluent nations like the U.S. and parts of Europe cannot agree to reduce their standard of living. Politicians suggesting that simply cannot expect to be reelected. The model outlined in this chapter represents a way for **developing and emerging countries to join the treaty, because they receive benefits according to the number of their population. At the same time developed countries can agree because they can continue their path of growth with reduced resource consumption**. In summary, allowing all nations involved to continue their desired growth with reduced resource consumption is the *political reason* for per capita-redistribution. German Chancellor Merkel and Indian Prime Minister Singh have basically agreed searching for a global policy that applies the per capita principle (Handelsblatt 2007).

The third reason for per-capita redistribution can be referred to as a *natural reason*. This draws on the point made by Walras, as explained in the literature review section above. It may be obvious to some and unthinkable to others, so a simple example should help to illustrate the underlying problem and the model proposed by Walras for land as a natural resource. The model, once its positive implications are scholarly understood, can be applied to evaluating and distributing the scarcity rent of almost any natural resource and, in the context of this chapter, of emission rights:

Pfizer Inc. is a globally operating company running production and development facilities around the globe. One of their facilities was located in the City of Karlsruhe in southern Germany. The company had bought land for its operations in 1958 and paid 50 Pfennigs per square meter. When it considered relocating operations, closing the factory and selling the land in 2008, the company asked for 500 EUR per square meter. The value appreciation for the land therefore was close to 200.000 %. Who, in a market economy, should be entitled to this return?

> Pfizer, of course, is entitled to the return from their economic, entrepreneurial activity, their performance and their achievement. The land value, however, cannot be attributed to Pfizer's activity but rather is influenced by many regional factors, for instance total demand, investment and capital accumulation in the region, which Pfizer only influenced marginally through its activities.[5] What caused the value appreciation of the land, the increasing demand for land in that region? **It is the economic activity of the people in general, not the economic activity of one particular person or company**.
>
> How can the people—in this case the citizens of the City of Karlsruhe—benefit from the land value appreciation? Walras' answer is precise: Grant land, in particular for such industrial holdings, in long lease contracts only, and with an adjustment clause make sure

[5] "Capital", as many readers are aware, in its original meaning roots in the Latin word "caput, capitis", for "head". Capitalism therefore means an economy based on abilities, on merits, not on mere ownership (that rather is the medieval or antique feudalistic approach). Consequently, everybody should be only entitled to the rent she or he can be held accountable and responsible for. In that sense, obtaining profit for something one is not accountable for (i.e. land value) can be characterized, according to Walras, as against the original idea and the actual meaning of capitalism.

that the lease increases if the land value appreciates. If the collected lease is redistributed per capita, all people in the region benefit.[6]

Coming back to our case, who is entitled and who caused the value of emission rights? It is based on supply, i.e. the scarcity of the absorption capacity of the atmosphere, and on demand. The supply is given by the natural limitation of the resource. What influences the price? Global demand! So who is naturally entitled to the rent deriving from its scarcity? The global population! This is what the model suggests, and this can be referred to as the *natural reason* or the natural justification of the per-capita redistribution.[7]

How much will be paid out per capita?

The auctioning mechanism described above yields 1 trillion EUR in revenues. If redistributed per capita globally to currently just over 7 billion, this means roughly 12 EUR per capita per month. This might not be a high amount for economically developed countries. But even there, for families at the lower end of the income scale, 12 EUR times four family members represent a significant increase in their available income.

For the poorest of the poor, however, 12 EUR per month means that they can pay for their most basic needs, for some it even doubles their income. Extreme poverty is defined as having less than one USD per day (Sachs 2005). Disposing of 12 EUR additional income will grant everybody access to the purchasing power they need to be an attractive target market for entrepreneurs supplying water and food, on a sustainable basis. In other words: **<u>Once these customers have the purchasing power, entrepreneurs can actually earn money by supplying clean water and food to them.</u> This means an immediate end to thirst and famine**.

One question arises in the discussion at this point: How can we organize the pay-out of 1 trillion EUR to 7 billion people? The answer is simpler than one would first expect. In economically developed countries there are highly developed accounting systems with bank accounts for practically everybody.[8] In several EU member states, citizens have a tax number assigned to them when they are born and lasting for their entire lifetime. For each tax number there is a bank account from and to which taxes are paid or reimbursed. This account can be used for the purpose of paying out the emission dividend.

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[6] It has been mentioned before that this is in accordance with capitalism (at least with its positive aspects and original meaning) and a market economy and works very successfully for instance in New York City. To some readers, however, this thought and its application to land and other natural resources may still be odd at first sight. Those I would like to point to the fact that some municipalities in Switzerland administrate their forests based on this idea. Wood is sold to private consumers, and the proceeds are being redistributed per capita by the end of the year.

[7] This reasoning is supported by Paine (1796), who argues that citizens should receive a payment reimbursing them for the fact that, due to land ownership by others, they cannot supply for themselves. One aspect of this *natural reason* can also be motivated, as some would argue was the reason for christian-democrat German Chancellor Merkel to agree with India on a per-capita orientation, by the preservation of nature, given to all men by God. This, of course, is a more religious than scientific account and therefore should not be addressed here further.

[8] The European Union (2013) even discusses the introduction of a Constitutional Right to a Bank Account.

The poorest the poor can have likewise access to bank accounts. Recent developments in banking to the poor show that effect. Microcredits may be subject to ongoing controversies due to some commercial banks putting debtors under immense pressure. What is relevant for the model presented here is that such systems have shown that is **technically and economically feasible to provide banking services to even the poorest of the poor**. In other words: If potential customers dispose of or are entitled to 12 EUR monthly, they can afford to pay 12 Cents for banking and account maintenance charge. Assigning account numbers will become even easier when a project currently carried out in India is rolled-out on a wider scale: Every Indian is getting her or his individual registration number (Nilekani 2009). On this basis bank accounts can be implemented for even the poorest of the poor.

There are countries in which neither a developed accounting system nor microcredits exist. In those countries the funds can be given to the national government with the requirement to ensure the establishment of banking services and providing food and water to the poorest. If in such countries we are facing corrupt regimes, the funds can be given to the UN Food and Agriculture Organization (FAO) for establishing such systems and providing food and water.

6.5 Advantages and Disadvantages of the Model

The implementation of the model yields several advantages, some of which will be enumerated here and then systematically summarized in a Table 6.1. **The main advantage in the context of this chapter is that *access to a sufficient amount of clean water is systematically secured through the per capita-payout of the scarcity rent of the atmosphere*, established by a transparent global auctioning process[9] and payouts that allow everyone to pay for water and therefore enable entrepreneurs to provide**. Other systematic advantages are:

1. Emissions are effectively reduced and the agreed climate protection goals are met (level 1).
2. An economic use of the atmosphere is incentivized and ensured, saving and avoiding emissions (level 2), because:
3. Products are more expensive the more emissions they cause. Ecologically superior products have a systematic price advantage.[10] Applying the model sets the correct price-signal, reflecting the actual scarcity and value of emissions rights.

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[9] Simplicity is important here as well as in other policies as it helps to avoid or at least reduce misuse through overcomplicating and deception.

[10] Today, in many cases, ecologically friendly products are more expensive and therefore economically less favorable. Example: Those travelling with the German railway system Deutsche Bahn can choose to "neutralize" emissions incurred for their journey by purchasing emission rights to offset these emissions. This might be a favorable marketing approach, but it does not avoid the fact that it is more costly to behave ecologically-friendly. The proposed model systematically ensures that **ecologically-friendly behavior is economically beneficial**.

Table 6.1 Benefits of the 3-level-approach

	Level I: sufficiency	Level II: efficiency	Level III: equivalence
Private households	1	3, 4, 5, 6, 10	11, 12, 13, 14, 15, 16, 17
Corporations	1	2, 3, 4, 5, 7, 8, 9, 10	11, 12, 13, 14, 15
Public households (countries)	1	4, 5, 6, 7, 8, (9), 10, 17	11, 12, 14, (15; red. Speculation), 16
United nations (global climate change prevention)	1	2, 3, 4, 5, 6	11, 12, 14 .

4. As a consequence, private households as well as corporations have an economic incentive to make ecologically friendly consumption and investment decisions (level 2).
5. Because of the incentives for corporations to employ technology reducing emissions (also level 2), **ecologically friendly technical innovations will experience faster amortization and higher demand**. Because private consumers have economic incentives to consume products causing fewer emissions (see advantage 3), **investments in such technologies pay off quicker than under the current policy**.
6. The relative advantage of investments in climate protecting technologies increases (due to advantages 3 and 5).
7. A global auctioning process (level 2) leads to *one unified global emissions price*. Corporations receive a reliable basis for their calculations and have no incentives anymore to relocate production due to differences in emission prices. That contributes to the **efficiency of global production**.
8. Emission rights, through the single global emissions price, are being purchased by those corporations and regions with the highest avoidance costs to offset emissions through new technology.
9. The model allows for agreeing on a **globally binding path for reducing emissions over decades**. This path can be **anticipated by corporations and provides a basis for planning their production and technology investments** (as well as for planning the costs for emissions not yet avoided).
10. **National governments** can focus on setting the economic policy framework. They **do not need to interfere with markets on a more operational level anymore**, today for instance through laws enforcing the insulation of buildings or the reduction of emissions from traffic by creating zones in which only certain vehicles may drive. The correct price signal from auctioning (level 2) implements the economic incentives to achieve the same effect (limiting emissions to the amount agreed on level 1) and more efficiently than countless single measures today. The redistribution (level 3) makes sure that **individuals and households are reimbursed for higher costs** (see *economic reason*), ultimately average living standards can remain unchanged.
11. **Economically developed countries** can agree to such a global economic policy because, as mentioned above, they **can continue their economic expansion** while at the same time reducing the amount of resources needed for a production of a given output (incentivized by advantages 3 to 6).

12. Emerging countries like India and China can agree to join such an economic policy, because the per capita redistribution means an influx of money (level 3) and a considerable economic catalyst for growth.[11] At the same time, the price signals for employing ecologically friendly technologies are in place here as everywhere else (see, advantages 3 to 6 and 11). This policy allows developing countries to have the growth perspective they need and at the same time the incentives to realize this growth in an ecologically sustainable way.
13. **"Per capita" redistributed is not the resource itself, but the <u>economic equivalent of the scarcity</u> that leads to its valuation**. Through the per capita redistribution, **everyone receives the *financial means for an average use* of the resource**, **allowing everyone an average use of the resource** in whatever products they may choose to consume (naturally, water being the first).
14. In effect, **those who use less than average, realize a financial net benefit. Because they effectively refrain from using the amount of the common they are entitled to** (see level 3, the natural justification of the per-capita redistribution), they **allow others, who through their economic performance and financial means can afford a beyond-average use of the resource by purchasing the goods and services produced utilizing the resource, to maintain their beyond-average living standard**. Those who use more than average are implicitly reimbursing those who use below average.
15. **The profit of any economic activity fully goes to those who perform it. The benefit of rents not caused by them is redistributed per capita.**
16. **The UN Millennium Goals are implicitly, systematically and sustainably achieved or even over-achieved by reducing or even eliminating poverty.**
17. The international climate negotiations **after the Warsaw Summit** suggest introducing **six funds and** have some **nations agree to give** not on a permanent basis but, e.g., **for disaster relief** 100 bio. USD until 2020 (rather than 1 trio. EUR annually as in this model). While disaster relief funds in general can be complementary and certainly represent an important element in the international climate change prevention architecture, they do not help to cure the shortage of funds for the poorest of the poor, often an immediate consequence of disasters. **The model proposed here foresees one fund that does not require the United Nations to beg again and again (and national budgets having to pay again and again) when disasters occur, and a sustainable payment securing clean water and food for all**.

Table 6.1 contains a summary and classification of the enlisted effects. The table is grouped by benefiters of each respective effect of the policy, i.e. private households, corporations, public bodies and the global climate situation.

The table reads as explained by the two following examples. Example one, the upper left field: private households benefit from advantage 1, i.e. level 1 (sufficiency). The effective reduction of emissions helps to avoid costs of continued climate change

[11] Some may argue that an influx of money to those countries means a reduction of funds in others. This model, however, represents a positive-sum policy, so an influx here does not necessarily lead to an outflow elsewhere.

(floodings, hurricanes, droughts etc.). Example two, lower right field: the UN and the world climate both benefit from advantage 14 (through level 3, per-capita-redistribution), i.e. **in the case of food shortages the UN today has to ask donor states for funds to purchase food to supply to the poor. In the case of future shortages in food and water supply, the UN will always dispose of the financial means to help those in need if they cannot help themselves**.

The proposed policy also bears a number of disadvantages. The first of them, perhaps like with all new proposals, is that it requires a minimum degree of awareness and global sense of responsibility among decision makers who can actually make it happen. Ideally, these are the heads of state of all nations represented by the UN. On a smaller scale it will suffice for a first step if the G20 or even the G7 or G8 agree on such a model. This requires an awareness in the population of these countries that the modification for the global climate change prevention architecture is necessary or can at least help to address some of the challenges at hand that otherwise cannot be solved. Only then will political leaders act.

Table 6.1 summarizes a number of advantages of the policy. Consequently, those who today benefit from the status quo, in particular from the scarcity rent, might have objections. Corporations may fear investments in clean technology even though the cost effects are mitigated through a foreseeable reduction path. This path allows companies to anticipate price changes and react years before emissions prices increase.

Another problem can be that consumers do not trust that the money will be reimbursed. And in fact the UN might have an incentive to keep more than necessary for administration.[12] This is one reason to keep this model and its implementation simple. Simplicity and transparency warrant that opportunities for deception and fraud are avoided.

Probably the biggest challenge is to convince corporations and countries benefiting from the status quo. To them, however, not much would change because the implicit price increase for oil represents a factor price increase and therefore affects all market incumbents to the same degree. They may, however, fear to lose some of the power relative to producers of renewable technology and fuels and therefore invest heavily in lobbies employed to convince both the populace and politics otherwise—or in renewable technology. The receptiveness of politics will determine the rent of investment in lobbies and therefore have direct influence on the relative superiority of investments in renewable technology.

Those challenges can be addressed if the negative repercussions of global warming increase so that the **G20 agree to implement a policy that effectively reduces emissions while at the same time avoiding social hardship. That is the intention of the model**. When the G20 agree on this policy, they have the power and the influence to cause other nations and corporations to join. The G20 represent about 80 percent of the global gross domestic product (GDP). The realization of the model will depend on the urgency and the relevance the G20 assign to resolving climate change.

[12] The author proposes a global consumption tax to cover the costs of the UN, including reimbursements to have tax-free amounts and to achieve an indirect tax progression (Presse 2009).

6.6 Further Questions

It takes energy to recover clean water from contaminated water, and globally energy is scarce. Does that not lead to a scarcity associated with clean water?

Yes, it does. This point is accommodated by the model by granting access to the purchasing power needed to create an economic demand for clean water (and for businesses to respond to this demand). In other words: If the needy dispose of the necessary purchasing power to pay for the clean water they need, their purchasing power will spark the entrepreneurial initiative (the technology is already available and routinely used) to produce and process clean water and the logistics to bring it to them, including the energy that is required for that.

Does not some water evaporate in the process of irrigation and therefore is not available locally anymore?

That is correct. However, even evaporated water remains a part of the global water circulation. The logistics for bringing water to the points where it is locally required for the basic needs of individuals, will be economically incentivized by these individuals disposing of the purchasing power to substantiate their physical demand with the financial means to pay for it.

What happens to pay-outs if emissions are reduced?

What will happen to the emission price when auctioned amounts are reduced over decades? That depends on the technology reactions of the industry. If volumes decrease while corporations do *not* invest in emission-saving technology leading to an unchanged or increasing demand, prices will increase as well. Increased payoffs to the people will be accompanied by increased economic incentives for investments in clean technology. If all other conditions remain unchanged, in particular if no investments in clean technology would be made, the price for emissions will go up as volumes for auctioning decrease. Unchanged or increasing demand will meet the reduced supply, emission prices increase, leading to increased incentives to employ ecologically friendly technology, i.e. which was and is the purpose the model in the first place (level 1).

Investments in CO_2–saving technology lets the demand for emission rights decrease. When a decreased demand meets a decreased supply, prices can remain stable, leaving auction revenues as well as payouts unchanged.

The model allows the UN to respond to changing conditions: if corporations comply and reduce their emissions over time in order to avoid paying increased emissions prices or if climate change demands for faster reduction, the amount of emission rights auctioned can be adjusted. The overall effect can be seen in Fig. 6.1: as volumes decrease, prices are likely to increase and the revenues from auctioning emission rights will remain stable or increase (in Fig. 6.1 from a total of 1.0 to a total of 1.2 trillion EUR) to match pay-outs to an increased population. The per-capita pay-out in this scenario can remain unchanged.

Is the amount of money redistributed enough for purchasing clean water? How is made sure that it is not used on other needs?

Currently emission rights are traded for just over 5 EUR per Gt due also to ineffective limitation of emissions and unenforced legal regulations, partly due to high complexity and lacking transparency of the current system. The calculations in this chapter are based on the assumption that limitations become effective and once such a scheme is in place, emission rights will trade at or above 20 EUR per Gt, yielding per-capita pay-outs around 12 EUR per capita per month. However, until that is the case, it is fair to ask if one quarter of emissions prices (5 instead of 20) resulting in a quarter of per-capita pay-out (3 instead of 12) is enough money for purchasing clean water.

The answer of course depends on the price of clean water. It seems fair to assume that most of those people in need for clean water today live in the poorest countries, resulting in the assumption that the overall price level is relatively low. As a consequence, based on the assumption that the poorest of the poor have less than one EUR to spend per day, the proposed scheme represents an income improvement of more than ten percent of the average individuals' income. Whether people will purchase clean water or something else will depend on what they are most in need of. Since water is the most essential nourishment it appears reasonable to assume that other needs will be only paid for if the basic need for water is satisfied.

Does the pay-out not lead to an increasing number of children and add to the population problem?

Some may argue that if the poorest of the poor have a guaranteed income that allows them survive, they will have more children than today. The opposite effect can be expected as well. Why do they have a large number of children in the first place? Old-age provision is the major driver of population in poor economies. If infant mortality is so high that parents need to have seven or more children to have the chance to see one grow up and have it care for them when they are old, there is a strong incentive to have many children. **If water and food security are guaranteed, the effect can be a reduced number of children. This is the effect empirically observed in all economies with increasing living standards. So this model represents an effective way to actually reduce population growth**, even without having to enforce one-child-policies like those in effect in some parts of China. In summary, the proposed model has the potential for being one approach to the global birth control suggested by Hardin (2009).

Some of the mineral oil is not burned but used for other purposes. Should these quantities be exempted?

A fraction of globally extracted oil is not used for combustion (heating, mobility etc.). So should the policy be applied to them as well? Even some of those not immediately burned for heating and mobility, might be burned later (such as oil used in tires burned when they become waste). The fractions not being burned but for instance used in medicine or for cosmetics are so small that following up on these quantities would cause more costs than benefits. Oil here is used in such small portions relative to the total product costs that the costs for emission rights will not increase prices of these products noticeably. This, by the way, is a good catalyst for products that do not heavily use fossil fuels. The price-signal in this case really solves the problem of allocating (and avoiding) fossil fuels globally.

What is the overall net effect on wealth distribution?

The wealthiest person on the planet can avoid increased costs by deciding to consume fewer products with high emissions and substitute them for products with lower emissions. Her or his living standard can remain unaltered at decreased emissions. The most likely outcome is that those who consume below average[13] will be net-receivers and **those consuming beyond-average will be net-payers. The climate policy proposed in this chapter systematically ensures an economic use of emissions while at the same time avoiding negative social repercussions** which can be observed at peak oil prices since 2008 (Presse et al. 2011).

Dividing the global population in thirds of consumption, measured in monetary value of goods produced and consumed using fossil fuels, the **lowest third** will definitely be among the financial benefiters. Members of this third cannot consume the average amount simply because they do not have the funds. In terms of CO_2 emissions they **abstain from using the average, effectively "allowing" the beyond-average consumers to consume more**. Unlike today, with the proposed policy they are being financially reimbursed for that.

The average user, typically perhaps the environmentally conscious consumer in economically developed regions in North America, Europe and wealthier parts of Asia, will consume "about" average. She or he will incur slightly increased costs through the fact that for the fossil fuels burned for their consumption the producers had to purchase emission rights for which the customers downstream are paying. The difference of the proposed policy is that they are actually being reimbursed by the per-capita payout, globally consistent. **While the lowest third is receiving a net financial benefit, the average consumer is about even, as increasing costs are matched by reimbursements**.

The **top third of global consumers are those who consume beyond average. Through the model they implicitly reimburse the lowest third (for allowing them to do so by consuming less), while at the same time maintaining their living standard.**

6.6.1 Illustrative Metaphor

To be even clearer, let us use a metaphor recommended by Wolfgang Eichhorn, once a leading European economist, and divide the top third further in three sub-sections. The lower two thirds of this top-segment consume relatively little compared to the "top of the top". In other words, Eichhorn says "the financial

[13] i.e. they consume services or goods produced with fewer emissions.

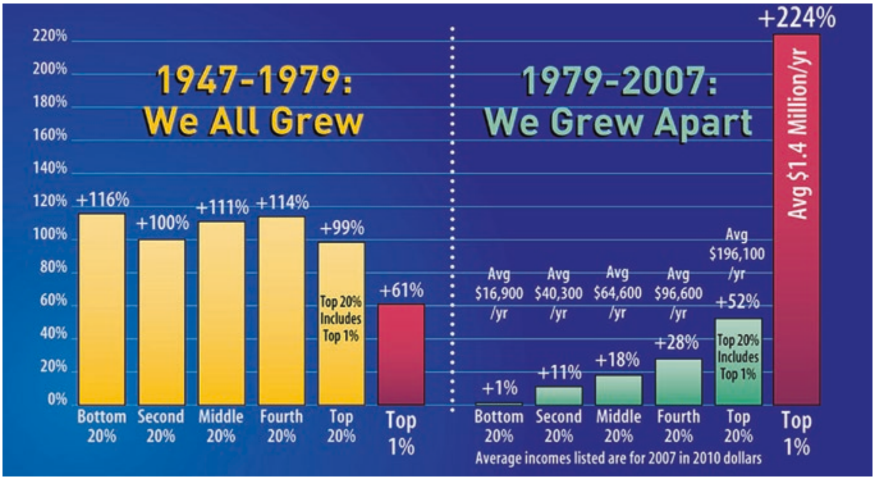

Fig. 6.2 Growth of family income in the US between 1947 and 2007 [Data and figure from the US Census Bureau (2012)]

burden will be carried by households with individuals purchasing goods equivalent to one hundred Rembrandts a year. With such a policy they will in the future be able to purchase one Rembrandt less." In fact, let us make an addition to that metaphor, using the following Fig. 6.2 to introduce **dynamics rather than a statistic notion on wealth** and its development. Figure 6.2 shows—for the U.S.—the development in income growth for the lower and higher incomes 1947–1979 and 1979–2007. It shows that in the first period (1947–1979) income growth was relatively balanced over all income quintiles, while in the second period (1979–2007) income growth was extremely imbalanced.

Statistical evidence suggests that the total income growth for the bottom quintile in the last 35 years is even negative. Fig. 6.2 shows that between 1979 and 2007 the lowest quintile gained only one percent (the top quintile 52 percent). Between 2007 and 2014, the lowest quintile has lost 10 percent while the top quintile lost 6 percent (U.S. Census Bureau 2014). Therefore the lower quintile in total has lost income in the years between 1979 and 2014 while the upper quintile has gained dramatically.

The effects of the model on this development can be explained in a two-step approach. In a first and simplified iteration building on the previous analogy, the top individual currently consumes the equivalent of 100 Rembrandts this year and 110 Rembrandts next year etc. Applying the proposed policy will put some part of the financial burden on her or him so that she or he can purchase only 109 Rembrandts next year, while ensuring the one billion poorest contemporaries have access to clean water. It is a more credible, more systematic and more sustainable approach than relying on the arbitrariness of the wealthiest one percent which, as can be seen by this example, will not suffer. In a second iteration, it is not at all certain that income growth for the top quintile will be lower after all when the proposed policy is applied. Income growth in the top quintile comes from entrepreneurial activity and capital returns, and these can increase when the poorest quintile is equipped with purchasing power and can afford to consume more than before.[14]

How can oil exporting companies and countries be brought to the table?

Corporations are legally bound to national law. Therefore it is important to have as many countries as possible agree on the policy. How can countries be brought to the table? The underlying principle is as follows: If there is no global warming or if global warming does not have the predicted severe negative effects, there is no need for a climate change preventing global policy as it is suggested here. If, however, the predictions are correct and mankind will face increasing natural disasters and the human catastrophes coming with them, the pressure on national states will increase up to a point where a sufficient number of states accepts their responsibility to overcome the national perspective, as pressure to act has increased in the past leading to the current but not yet sufficient global efforts. To put it in a nutshell: Man learns through insight or by disaster. The proposed model addresses the part of man learning through insight and accommodates those who learn by disaster.

Does the comparison of capping emission rights with fishing quota hold in the absence of realistic substitutions for fossil fuels?

Are there no realistic substitutions to fossil fuels? If there are not, the conclusion implied by this question is correct and governments may renege. If there are, however, realistic alternatives, then the pressure to reduce the use of fossil fuels systematically to prevent further climate change may be immanent. The question whether there are realistic alternatives to fossil fuels cannot be answered in this chapter. It is one assumption of the model presented here that there are realistic alternatives, whether through solar power, wind power, water power, other renewable sources of energy, other efforts to reduce the need for fossil fuels and, ultimately, new sources of energy (for instance nuclear fusion).

Will this policy affect living standards and growth in industrialized economies?

Through reimbursement and income distribution effects mentioned before, all consumers can consume the same levels of goods and services as today and even more than today, then produced with technologies causing fewer emissions.

[14] Some readers may argue that this is a policy for wealth redistribution. However, the suggested policy does not redistribute already existing wealth but portions of future wealth. The primary purpose is to let the public benefit from the scarcity rent of a common. So a balance is gradually reached. Piketty (2014) has argued that taxing high incomes and fortunes can solve the extreme imbalance of income. The solution in this chapter presents an additional and slightly different approach by addressing one of the causes of extreme imbalance, i.e. gatekeeper rents from the scarcity of commons.

6.7 Summary and Closing Remarks

The Warsaw Climate Change Conference is closing while this chapter is finalized. Among the findings of Warsaw and the preparations for the Paris Summit in 2015 is the agreement that six funds shall be established until 2020, e.g. for disaster relief (United Nations 2013; Bojanowski 2013). What about the ongoing disaster of famine and thirst, threatening one billion fellow men and killing tens of millions annually? Let alone coming to an agreement on binding global limits for emissions that allow all economies to progress and reimburse the poorest of the poor. This is not the ecological, economic and social sustainability put forward through the model developed here.

Why is such a model not yet being discussed on a wider scale? It has just now been published and additional applications are found every day. Its implementation however, as mentioned above, will largely depend on the development of the climate situation in the forthcoming years. If the IPCC is wrong and anthropogenic climate change is negligible, then such a policy is not needed. If, however, the forecasts of the IPCC are not entirely wrong, we will see more consequences of our regardless approach to nature and, ultimately, and increasing need to take global action on climate change while avoiding additional social hardship. This model is combining both elements.

The policy allows addressing many of the problems arising from climate change, including the problem of water security. After its implementation on emission rights, resolving future ecologic challenges result in a higher income for those most in need. **Everybody, even the poorest, will dispose of the financial means to pay for clean drinking water. Therefore entrepreneurs will have the incentive to provide clean water and food**. This resolves one of the most threatening issues of this civilization's development currently. It is an unnecessary problem because on this planet there is enough drinking water for all.

Desalination and purification of water are costly. Supplying sufficient purchasing power to the neediest is imperative if we do not wish to tolerate an ongoing human catastrophe permanently. In fact, the good news is that we can virtually change it in an instant. All the necessary resources to resolve this crisis are available. What we need are strong supporters for the proposed model within the UN and national governments of the G8, better the G20. Any global citizen who wishes this problem to be resolved is welcome and invited to contribute to the process.

Acknowledgments The author thanks Sonja Koeke, University of Hamburg, and Dr. Ludwig Paul Häußner, University of Koblenz-Landau, for their valuable feedback and comments.

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Chapter 7
Trans-boundary River Basin Management: Factors Influencing the Success or Failure of International Agreements

Hojjat Mianabadi, Erik Mostert and Nick van de Giesen

Abstract Water is an environmental, political, cultural, historical, and economic natural resource that is of vital importance for human life. As many water resources are shared by more than one country and since there is no substitute for water, water has become a security issue. In this paper, we provide an overview of the factors that may potentially increase conflict among riparian countries and affect the success or failure of international agreements in addressing trans-boundary water management issues. Additional insight into these factors can assist in designing resilient water treaties, decrease the likelihood of the collapse of international water agreements, and consequently decrease the potential for conflicts among riparian countries.

Keywords Shared water resources · International treaties · Trans-boundary rivers · Conflict and co-operation

7.1 Introduction

Water is a significantly political natural resource (Donahue and Johnston 1998; Elhance 2000) that can be compared with other natural resources such as oil. However, it differs from oil in that we cannot live without water for more than a

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_7

few days (Ettehad 2010).[1] Moreover, there is no substitute for water, and it is becoming increasingly scarce.

Due to these factors, water has become a security issue. Iyob (2010) mentions three security aspects: biophysical security, related to ecosystem and environmental threats; socio-economic security, such as food security and hydropower production; and geopolitical security, related to international relations and national security. Often, upstream countries use water to gain more power, and downstream countries use power to obtain more water (Warner 1992, 2004). The potential for conflict is therefore large.

There are various approaches to the relationship between natural resources and conflict. Neo-Malthusians believe that, due to the rapidly increasing global population, resource scarcity will lead to future conflict. The so-called "cornucopians", however, have a more optimistic perspective and contend that technological innovation can surmount the scarcity of resources. The "distributionists" believe that conflict is a cause, rather than the result, of natural resource degradation. Finally, neoclassical economists place emphasis on the institutions to maintain natural resources and to prevent conflict (Homer-Dixon 1994, 1995; Gleditsch 2003; Hensel et al. 2006; Frerks et al. 2014). While linkages between natural resources and conflict may be "indirect at best" (Frerks et al. 2014), we believe that these linkages exist and that increasing scarcity as a result of climate change, population growth, and other changes will test the viability of existing management institutions.

Currently, there are approximately 276 trans-boundary basins, which are shared among 148 riparian countries, extend over a total 61,962 million km^2 of the earth's surface, and host more than 2.7 billion people (Wolf et al. 1999; UNESCO-IHP ISARM 2009; De Stefano et al. 2012). Complicating this issue of water sharing is the lack of international law. Although, with the passage of time, public awareness regarding international sharing has increased, the international community has not succeeded in developing a comprehensive international water law for the management of shared trans-boundary basins. There is no internationally accepted allocation mechanism for sharing water resources or their benefits (Wolf 1999). Moreover, more than half of the trans-boundary basins are without any type of cooperative institutional framework (Ansink 2009). Treaties that do exist are often not implemented and, if they are, may collapse when circumstances change, e.g., when unforeseen droughts occur.

The study of Hensel et al. (2006) regarding the river claims data coded from 1900 to 2001[2] supports the argument that water resource scarcity and a minimal level of institutionalization significantly increase the likelihood of conflict and militarized disputes over shared river basins. Conversely, institutions designed to settle conflict will decrease the likelihood of conflicts (Hensel et al. 2006).

[1] Other differences are that oil is a central motor of capitalist production and consumption, and the profits deriving from oil will continue to be much more than those from water. Moreover, oil is much more characterized by a high degree of monopoly (Selby 2005).

[2] This data is available from the Multilateral Treaties of Pacific Settlement (MTOPS) database, which has been collected by the Issue Correlates of War (ICOW) Project and includes river claims in three regions: the Americas (North, Central, and South America and the Caribbean), the Middle East, and Western Europe. It is available at http://www.icow.org.

There are different attitudes about the relation between trans-boundary water conflict and trans-boundary water cooperation. Some researchers separate conflict from cooperation and examine these two terms as distinct phenomena (Wolf et al. 2003; Yoffe et al. 2003; Wolf 2007). Some others contend that trans-boundary conflict and cooperation are aspects of trans-boundary water *interaction*, and rather than separating the two concepts, assert that conflict and cooperation co-exist (Zeitoun and Mirumachi 2008; Zeitoun et al. 2011). Generally, negotiation over shared water resources consists of both conflict and cooperation—*learning and fighting* (Warner and van Buuren 2009)—and the simultaneous consideration of these two processes is key to understanding progress in river management interventions and may improve the quality of decision-making (Mirumachi and Allan 2007; Warner and van Buuren 2009).

In this paper, we briefly review some significant challenges of trans-boundary river basin management. In addition, we provide an overview of the primary factors that can increase conflict among riparian countries. We also survey the principal reasons turning conflict into cooperation and influencing the success or failure of international water agreements. Obviously, insight into these reasons is advantageous when designing resilient water treaties and can decrease the likelihood of the failure of a treaty.

7.2 Utilization of Trans-boundary Rivers

Shared water resources among states can be a source of both conflict and cooperation (Mianabadi et al. 2014). Water resources management is directly and indirectly associated with socio-economic, political, environmental, industrial, and security aspects of a society. A water resource system involves influencing the interaction of three sub-systems: the ecological and natural sub-system, the socio-economic and cultural sub-system, and the institutional and legal sub-system (Loucks et al. 2005). These sub-systems continuously influence each other in that socio-economic and cultural factors influence the development of institutions and regulations, which subsequently influence the natural environment in the basin, which then influences the basin's economy and society. For sustainable water resource management, all three sub-systems should be simultaneously taken into consideration in any planning and policy making. Various qualitative and quantitative attributes and many different stakeholders should also be considered. Hence, a water resource system cannot be managed and planned by only one expert or policy maker.

In addition to the aforementioned sub-systems, the geopolitical sub-system must be considered. Geopolitically, water cannot be separated from politics and security (Iyob 2010). In western Asian countries, due to the delicate position of ethnic and religious groups and their economic reliance on the water resources, governments continuously attempt to obtain the maximum share from trans-boundary water resources in order to satisfy these groups. This has exacerbated water disputes within the region (Korkutan 2001). For instance, one of the primary goals of Turkey in promoting the South-East Anatolian Development Project (*Guneydogu Anadolu Projesi*: GAP) is developing the economy of the areas inhabited by the Kurdish ethnic group in order to dissipate separatism (Hakki 2006). Moreover, some riparian countries perceive the water resources as significant strategic assets (Korkutan 2001). For example, based on the 1987 security protocol between Turkey and Syria in the Euphrates basin, Turkey guaranteed Syria an annual average minimum flow of 500 million cubic meters per second. In return, Syria would cooperate on security matters related to not supporting the *Partiya Karkerên Kurdistan* (PKK), known in English as the Kurdistan Workers' Party (Burleson 2005; Ansink 2009). Hence, policy and decision making in trans-boundary basins may affect political stability and the national security of riparian countries. Accordingly, water resources management in trans-boundary basins is more sensitive and complicated than in national and local basins.

Various principles of international water resources management have been employed by riparian countries to support their claims, but some are more widely recognized and utilized more frequently in international conventions and treaties. The more familiar are the principle of equitable and reasonable utilization; the obligation not to cause significant harm; the principles of cooperation and information exchange; the principles of notification, consultation, and negotiation; and the principle of peaceful settlement of disputes (Rahaman 2012). These principles form the foundation of the 1966 Helsinki Rules on the Uses of the Waters of International Rivers (Helsinki Rules) and the 1997 UN Convention on the Law of the Non-Navigational Uses of International Watercourses (UN Watercourses Convention) (Rahaman 2009; Loures and Rieu-Clarke 2013). Generally, upstream riparians are inclined to favour the principle of equitable and reasonable use, whereas downstream riparians prefer the principle of not causing significant harm (to themselves as downstream users) (Odom and Wolf 2011).

In spite of the fact that international water treaties can be traced back approximately 800 years, modern international water law has essentially developed only within the last two centuries (Dellapenna and Gupta 2009). However, the world community has not yet succeeded in agreeing on a universally applicable treaty to regulate the utilization and protection of international water resources (Salman 2007). Among several international water laws and conventions, the Helsinki Rules (1966), UN Watercourses Convention (1997), and Berlin Rules (2004) are more well-known and have been referred to in several basin-specific water agreements.

7.3 Failure of International Water Treaties

As previously discussed, trans-boundary river basin management is closely associated with political, military, security and socio-economic issues. It is without question that neglecting these issues can considerably affect the resilience of water treaties. Moreover, similarities and differences in economics, politics, geography, socio-culture environment, language, religion and governmental structure between riparian countries can increase or decrease water cooperation in trans-boundary river basins.

Of the world's 276 international river basins, 158 do not have any type of cooperative mechanism (Ansink 2009). However, the primary question of this study is why many of the signed water treaties, such as the Indus River Agreement of 1960, the Nile River Agreement of 1959, and the Euphrates River Agreement of 1987, have not been resilient. What are the main reasons causing non-resilient water treaties? Clearly, each international river exhibits its own climatic, cultural, political and historical features; consequently, we are unable to create a comprehensive list of the factors causing the failure of water treaties and agreements. For example, the reasons for failure of agreements between Turkey, Syria, and Iraq over the Euphrates and Tigris Rivers are different from those causing breakdown in Amu-Darya Basin in Central Asia. Yet, we can identify several broad categories of reasons.

7.3.1 Hydrological Conditions

The uncertainty of river flows is a major feature of water resources affecting failure and instability of water agreements. Water agreements that are not sufficiently flexible to adjust to the hydrological variability of river flows face challenges and can result in disputes. Historically, extreme events of water conflict have been more frequent in regions characterized by high hydrological variability (De Stefano et al. 2012). This issue can potentially increase the likelihood of a treaty breach. Variability of water flows can also create risks for the stability of agreements because a change of conditions may cause riparian countries to change their preferences and reduce incentives to comply with existing agreements (Drieschova et al. 2008). For instance, the Rio Grande/Rio Bravo basin, forming more than half of the border between México and the USA, is under the international 1944 USA-Mexico Water Treaty. Due to continued diminished flows and drought in the 1990s, dispute between the USA and Mexico over three shared rivers increased and stimulated them to renegotiate the treaty (Gastélum et al. 2009). Trans-boundary river basins not governed by resilient water treaties or adaptive resource governance and experiencing flow variability may be more vulnerable to conflict (De Stefano et al. 2012).

Several studies indicate that a significant reason for the instability of many water agreements is that water allocation is based on average river flow, which is the case in many current agreements (Drieschova et al. 2008; Ansink 2009). Otherwise stated, ignoring the variability of river flows may escalate the potential conflict among riparian states. Conversely, studies reveal that water allocation based on percentage of flow is a mechanism with a substantial degree of both flexibility and enforceability and can considerably mitigate the negative impacts of hydrological variability of rivers flow (Drieschova et al. 2008). However, only a minority of current international water treaties take the variability of hydrological conditions and river flow into consideration (Giordano and Wolf 2003).

7.3.2 Climate Change

Climate change, as a potentially destructive phenomenon, can affect water availability, timing, quality, and demand (Cooley et al. 2011). It can also affect precipitation patterns, average river flow, water availability, and extremes such as flood and drought (Bates et al. 2008). Using 12 regional climate models, a 10–40 % increase in runoff in eastern equatorial Africa, the La Plata basin and high-latitude North America and Eurasia has been predicted by the year 2050, as well as a 10–30 % decrease in southern Africa, southern Europe, the Middle East and mid-latitude western North America (Milly et al. 2005). According to Palmer et al. (2008), the Senegal River may experience a decrease in river flow of approximately 40 %. However, there are large uncertainties in climate models.

De Stefano et al. (2012) studied the relationship between climate change, river flow variability, and institutional capacity to handle resource variability in order to identify the areas at potential risk of future hydro-political conflict. Their study revealed that among 276 trans-boundary rivers, 24 have a high potential risk of conflict under current variability, in most cases associated with poor water governance, low institutional capacity, and present water variability. Most of these are located in northern and sub-Saharan Africa (De Stefano et al. 2012). Considering future water variability and potential climate change impacts by 2050, trans-boundary basins in other regions, such as Central Asia and Eastern Europe, may also experience the highest level of risk of conflict (De Stefano et al. 2012). Increasing variability and changes of mean river runoff may result in or increase tension and potential conflict between riparian states if the basins are not governed by adaptive institutions. Obviously, water treaties that have not been designed considering current and future variability and are not flexible enough to deal with new hydrological realities may face serious challenges in the future.

7.3.3 Lack of Comprehensive Water Law

The lack of consensus on a comprehensive definition of international water law is another important factor for the failure of water agreements. As mentioned earlier, there are several water rules and conventions as well as principles for trans-boundary river utilization. Some of the most cited principles in negotiations and treaties of water conflicts include:

- the principle of historic use,
- the principle of real demand (irrigation, environment, domestic, industry),
- the principle of equitable and reasonable utilization,

- the obligation not to cause significant harm,
- economic principle,
- absolute territorial sovereignty and integrity.

Efforts to create an internationally acceptable and comprehensive water law for trans-boundary river basins have not yet been successful (Swain 2001), hence, each riparian country refers to the principles that best support its individual claim. In the Nile basin, for instance, which is shared among eleven riparian countries, Egypt and Sudan are the largest water consumers and their claims are disputed by the other riparians (Ansink 2009). Egypt defends its claim based on the principle of historic use and right, whereas Sudan and Ethiopia, both located upstream from Egypt, defend their claim by referring to the principle of equitable and reasonable utilization (Ansink 2009). This issue has been an increasing dispute among riparian states. The conclusion of the Nile Basin Cooperative Framework Agreement in May 2010 has not altered this situation because Egypt and Sudan refuse to sign.

7.3.4 Ambiguity in International Water Laws

In addition to the previously mentioned factors, additional causes of the failure of international water laws to resolve dispute is the ambiguity in some articles of international water law. As an example, Article 5 of the UN Watercourses Convention focuses on equitable and reasonable utilization of shared water. Article 7, however, refers to the obligation to not cause significant harm to other riparian countries. Since no quantitative attributes and criteria are mentioned for equitable and reasonable utilization without causing significant harm to other riparian states, each riparian country interprets these Articles in its own manner. Stated differently, the various interpretations of the riparian states regarding the relationship between equitable and reasonable utilization and the obligation to not cause significant harm is a major reason for conflict among some riparian countries (Salman 2007). For instance, in the case of the Euphrates-Tigris Basin, Turkey bases its arguments on Article 5 while implementing the GAP project, indicating that it is using the rivers based on equitable and reasonable utilization. Syria and Iraq, however, base their arguments on Article 7 and claim that Turkey is causing significant harm to the downstream countries (Korkutan 2001).

Moreover, it is obvious that activities of one riparian state on the shared river basin may harm other riparians (Salman 2007). The lack of an explicit definition of ‘significant harm’ appears to be another ambiguity in these rules.

7.3.5 Hydro-hegemony

One key element of trans-boundary water conflict that should also be considered in water disputes is the impact of asymmetry, asymmetry in power being a fundamental aspect of hydro-politics (Daoudy 2004). Asymmetry in political, military, economic, etc. power between riparian countries may prevent cooperation (Ansink 2009). Zeitoun and Warner (2006) explain this in terms of hydro-hegemony theory, which focuses on the role of power asymmetry for water conflict in trans-boundary river basins. Otherwise stated, "*Hydro-hegemony is hegemony at the river basin level*, *achieved through water resource control strategies such as resource capture*, *integration and containment*" (Zeitoun and Warner 2006). Hydro-hegemony of Egypt in the Nile basin, Uzbekistan in the Aral Sea basin, Israel in the Jordan River basin, and Turkey in the Euphrates and Tigris Rivers basins are among these cases. For instance, despite the fact that more than 95 % of the Nile basin is located outside of Egypt, 97 % of the Nile water is exploited in Egypt (Mokhtari and Ghaderi 2008).

Generally, treaties that are forced on the non-hegemonic riparians are less likely to be supported by them and may prove unstable in the long term. Nonetheless, even these treaties may provide some benefits to the non-hegemonic riparians, who may consequently agree to such a treaty for pragmatic reasons (Haugaard and Lentner 2006). Stated differently, asymmetries in power do not necessarily determine the results of negotiations but negotiation outcomes remain temporary and bilateral, and the overall benefits lie in the hand of the most powerful riparian (Daoudy 2009).

7.3.6 Non-integrated Water Management

The lack of attention to integrated water resources management (IWRM) may decrease the efficiency of utilization, and the basin may be confronted with numerous problems. Due to the high number of local, national and international stakeholders, different water governance systems, and sharing among two or more than two states, IWRM in shared and trans-boundary basins is even more difficult than in a national context. Lack of trust between riparian countries, a limited exchange of information and data, and political and security considerations are some of the primary issues facing IWRM in trans-boundary river basins. Moreover, historical disputes among riparian countries, a focus on water supply rather than water demand management, disregarding economic, socio cultural and political attributes as well as multi-stakeholders' participations in decision making (Mianabadi et al. 2011), are other significant factors. However, some studies concluded that multi-stakeholder platforms for IWRM rarely solve practical problems but should not be dismissed for their apparent failures (Warner 2006).

7.4 Conclusion

In this paper, some of the principal issues of trans-boundary river basins management have been briefly described. The lack of attention to these issues may result in or increase tension and potential conflict between riparian states. Additionally, some important reasons for the failure of international water treaties and agreements have been surveyed. Understanding these factors and providing the necessary solutions to address these issues can be effective for designing resilient water treaties that will need to be developed in the future. Clearly, since each trans-boundary basin exhibits specific hydrological, political and socio-economic characteristics and conditions, influential factors are not limited to the mentioned factors. However, different effective reasons that pose a threat for cooperation and decrease resiliency of water treaties should be individually studied for each international river basin. The factors mentioned in this paper are among the most significant factors causing conflict and instability or failure in water negotiations and agreements in different real case studies. Investigating the causes of instability of water treaties between two or more countries in trans-boundary river basins is a first step towards decreasing the potential conflict among riparian countries in the mid- and long term and may facilitate the design of resilient water treaties by means of specific adaptive governance mechanisms.

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Chapter 8
Drinking Water Treatment and Supply in Developed Countries in 2045—Where Will We Be?

Peter M. Huck

Abstract An adequate and secure drinking water supply is one of the key components of infrastructure in developed countries. This infrastructure has been developed over a number of decades and will continue to evolve. For those who provide this vital service, it is important to think about what things may look like several decades from now, to facilitate intelligent planning and development. A glance at the past tells us that it is impossible to predict specific technological developments that may occur several decades from now. However the basic paradigm that describes public water supply (choose the best possible source, design and operate adequate treatment, provide secure distribution, conduct adequate monitoring, and respond appropriately to an adverse monitoring result) will still be relevant. Each of these five elements has technical, institutional and human aspects that are all important for the development and maintenance of robust systems. Using this paradigm, this article discusses important trends that can guide us in developing and improving water supplies over the next several decades.

Keywords Drinking water supply · Robustness · Climate change · Future challenges

8.1 Introduction

The provision of a safe and adequate municipal water supply is a hallmark of developed countries and is one of the key pieces of infrastructure such as transportation and electricity that many of us take for granted but that has the power to be seriously disruptive when not functioning properly. The provision of municipal water supply has developed over the past several centuries and the key physical components consist of a source (surface water or groundwater), a treatment facility and a distribution network to provide the water to homes, factories and businesses, and in some countries, agricultural users.

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_8

By nature, the provision of municipal water supply is a conservative “industry”. Major components of the physical infrastructure are built to last for periods of 30, 50 or even 100 years. Because public health is at stake regulatory authorities are reluctant to approve the installation of untested or inadequately tested processes or equipment. Further, because the system must process relatively large volumes (on the order of the 100 L per person per day, or more) treatment innovations must be very inexpensive on a unit cost basis (i.e. per cubic meter processed) to have a chance of being implemented.

Like every other industry and sector, however, the water supply sector is undergoing substantial changes and will continue to do so. To help us prepare to continue to meet society’s needs and expectations for a physical infrastructure that by nature has such a long design and operational life, it is important that we look ahead and consider long-term trends so that we can make the best possible decisions for the future. The purpose of this paper is to address this matter in a heuristic way and to provide some broad guidance. It is not only the physical infrastructure that is important, but also the organizational structure that operates it and the individuals within the organization.

The reader may ask: why choose the year 2045? A timeline of approximately 30 years was deliberately selected to be both long enough to require thinking beyond trends that are currently evident and also short enough that some younger readers may still be working in the field at that time!

It is important to note that this chapter does not attempt to assess the potential or the consequences of transformational world events such as a total breakdown of current technology or major conflicts, be they over water or something else. In other words, it assumes a “best case” or “business as usual” situation involving gradual evolution of technology, practices and society. The potential impacts of climate change, which were addressed in much more detail in various presentations at the 6th International Conference on Water Resources and Environment Research held in Koblenz, Germany in June 2013, and that are included in this and other volumes published from the conference, are considered in only a general way. In particular, it is recognized that a municipal water supply represents one of the “users” of water within a given catchment or subsurface capture zone, and that it will be impacted by shifts in baseline quality and quantity of the source water, and by increased occurrence of extreme events. These are discussed briefly later in the chapter. In the arguably “best case” scenario considered by this chapter, the provision of an adequate and safe municipal water supply remains a crucial activity and will be subject to challenges.

8.2 Looking Backwards (to Help in Looking Forward)

Before looking forward, it is helpful to take a look in the rear-view mirror, so to speak. What this does is point out some of the difficulties in predicting developments in the future.

In the early 1980s, society and technology in developed countries were much different than today. To give just a few examples, there was no e-mail and wireless, global warming was not a term in common use, and the world power balance was much different—for example, the Iron Curtain was still in existence. A simple example of changes in technology is the Walkman® tape player. It was a revolutionary device when it appeared on the market around 1980, however production ceased several years ago.

In terms of the priority areas in drinking water supply, disinfection by-products (and in particular trihalomethanes, by-products of chlorination) had been the major water quality focus in the 1970s. By the 1980s, with the recognition by the water industry that *Giardia lamblia* was a pathogen of concern, the focus switched back to disinfection. An additional protozoan pathogen, *Cryptosporidium parvum* reemphasized the focus on disinfection as a result of the contamination incident in Milwaukee, USA in 1993 (e.g. MacKenzie et al. 1994). This in turn was a factor in the adoption of UV technology for disinfection/inactivation around the turn of the millennium. In the province of Ontario, Canada, the tragic microbial water contamination incident in Walkerton in May 2000 (Hrudey et al. 2003), led to a number of regulatory changes. The Ontario Safe Drinking Water Act, passed in 2002, included more emphasis on proper management of water supply systems, and a significant shift from voluntary to mandatory compliance. The Clean Water Act, passed in 2006, provided legislation regarding source protection. It is thus evident that every few years the focus in the water industry has changed, generally in ways that were not predictable.

Considering technology in general, everything moves much faster than it did 30 years ago and we all have much more information. (Whether or not it is better information in all cases is another question.) The public, who are the ultimate consumers of our product, also have more information and can mobilize more quickly and easily to become involved in a particular matter related to water supply. Will things be even faster in 2045? It is difficult to say whether revolutionary new communications technologies will emerge, or whether there will simply be evolutionary changes to current technology. For example, once the telephone was invented and made real-time conversations at a distance possible, improvements to the technology were of a smaller nature over a number of decades.

The paragraphs above indicate that individual technical developments are not predictable. However, as noted previously, the provision of an adequate and high quality drinking water supply will remain important to society. The areas of emphasis within that may shift, and certainly, technology *will* shift. We therefore need a paradigm to frame the issue. One such paradigm is presented in the next section.

8.3 A Paradigm for Municipal Water Supply

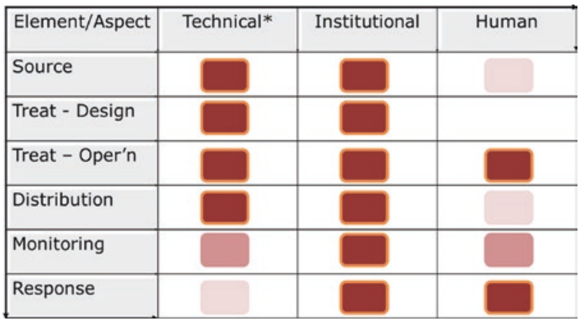
As part of his participation as an expert witness in Part 1 of the Judicial Inquiry following the tragic water contamination incident in Walkerton in 2000 the writer proposed the following five elements as being essential for the provision of municipal water supply: source, treatment, distribution, monitoring and response. This paradigm was then used to describe the multi-barrier approach for water systems outlined in Sect. 4.2 of the Part 1 Inquiry report (O'Connor 2002). The principle can be elucidated as follows:

- choose the best possible source (from both a quality and quantity perspective),
- design and operate adequate treatment,
- provide secure distribution,
- conduct appropriate monitoring, and
- respond quickly and appropriately to an adverse monitoring event.

Providing adequate attention to each of these five elements can provide an adequate and safe water supply. More sophisticated paradigms can certainly be constructed, such as the World Health Organization's Drinking Water Safety Plan approach, however the simplicity of this one allows it to be easily grasped by non-specialists and members of the public.

The previously mentioned multi-barrier approach, which can be referred to as "defense in depth", is an important concept for water supply systems, as is the concept of robustness or resilience of the system. In addition, water supply systems consist not only of physical aspects (such as a pump or valve or a river that is the source), but also of institutional and human aspects (Fig. 8.1). Figure 8.1 is of course a 5 × 3 matrix (in fact a 6 × 3 because treatment has been divided into design and operation), and the darkness of the shading in each cell is a qualitative representation of its importance. For example, the need for humans to make rapid and potentially important real-time decisions is not important in the design of treatment facilities, however can be crucial for their proper operation. The institutional component includes the system's management structure as well as the regulatory environment in which it operates.

The importance of the non-technical aspects was well illustrated by the actions of the Ontario Ministry of the Environment following the Walkerton incident. Operator training was substantially increased and the Safe Drinking Water Act introduced an accreditation system to strengthen the organizational responsibilities of managers and owners, and support for the water supply system.



*Physical aspect in the case of Source

Fig. 8.1 The 5 elements of a municipal water supply system and their 3 aspects

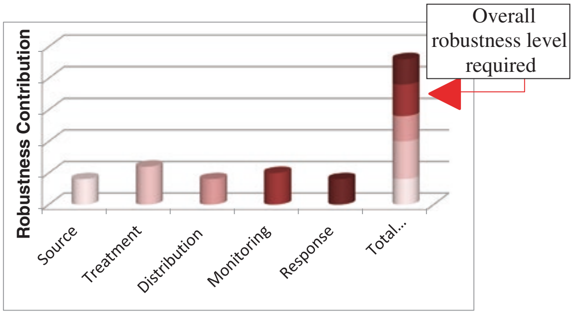


Fig. 8.2 A simple additive robustness model

The concept of robustness is extremely important for water supply systems. There are various definitions for robustness, as documented for example by Li (2004), however a useful definition of a robust system is one that functions very well under normal circumstances and deviates minimally from this when challenged (Huck and Coffey 2004). All three aspects (technical, institutional and human) are important for robustness.

Figure 8.2 casts the five elements in terms of a very simple additive robustness model. The model assumes that the robustness of each of the five elements can somehow be quantified using the same measurement scale. In this model, the robustness of the overall system is simply the sum of the robustness of each of the five elements (all with equal weighting). In the example shown the overall system robustness exceeds that which has been established using some criterion.

The purpose of Fig. 8.2 is to illustrate that, although some minimum level of robustness is required in each of the elements, weakness in a particular element can be overcome by strengthening one or more of the others. For example, if the only raw water source available to a particular community is of poor and variable quality, extensive treatment and vigilant monitoring can provide an overall acceptable level of robustness to the system. Thus, in this case the concept of the chain only being as strong as its weakest link does not strictly apply.

The next sections of this article offer comment on future trends for the first three of the five elements: the source, treatment, and the distribution system. For reasons of space, a separate discussion of the remaining two elements (monitoring and response) is not included, however the impact of expected developments in monitoring on the management of distribution systems is addressed.

8.4 The Source—Viewing Climate Change in the Context of Robustness

As stated earlier, the object of this article is not to address climate change in any detail, rather simply to consider in a general way its impact on drinking water supply systems. Figure 8.2 indicates that, should climate change, for example, decrease the robustness of a given raw water source, this will require increased investments in other elements of the system.

The impact of climate change can basically be classified as impacting either quantity (more or less water available) and/or quality. The latter can consist of a long-term evolution in baseline raw water quality, and/or more frequent/serious fluctuations in raw water quality associated with storm events. Expected quality fluctuations would include increases in sediment load (turbidity) as well as potentially accompanying peaks in microbial and chemical contamination.

Long-term evolutions are easier to deal with because they are more easily incorporated into the planning cycle. An immediate consequence that planners can draw is to incorporate increased flexibility into treatment plant hydraulic design and layout, to facilitate future additional treatment processes that may be necessary to deal with long-term changes in incoming water quality.

The short-term changes may be more difficult to deal with. Although the water industry is increasingly adopting the recognition that treatment design must be able to deal with nontypical raw water quality rather than simply average conditions, this of course costs money and so there is some natural resistance to incorporating this. The immediate greatest danger to public health of course is in terms of microbial water quality. A worst-case scenario would be a bolus of pathogenic microorganisms passing through a treatment system and on to consumers because the plant was unable to cope with an adverse raw water quality event. One approach that may be helpful in persuading those responsible to make the necessary investments is Quantitative Microbial Risk Assessment (QMRA) as described by Haas et al. (1999). A QMRA model developed by Health Canada (Douglas 2011) allows scenarios to be run in which incoming pathogen levels can be varied and various treatment processes operated sub-optimally or disabled. The model then calculates the impact of these on pathogen concentrations in the finished water and provides estimates of risk to public health.

Another important consideration raised by the increased frequency and severity of extreme weather events due to climate change is the potential physical damage to water treatment facilities. Usually these are located close to the source and in the case of a surface water plant often only a few meters above the level of the lake, river or reservoir. This makes sense because it minimizes the amount of pumping required to bring the water to the head end of the plant, from whence it typically flows by gravity through the treatment process before being delivered by the high lift pumps to the distribution system.

If the treatment plant becomes flooded, however, the whole system fails. Therefore, going forward it will be important to assess this vulnerability for individual treatment facilities, perhaps moving some of them to higher ground as part of an overall upgrading process, with the full understanding that this will increase pumping costs on an ongoing basis. In certain cases, it may be possible to obviate this by measures such as constructing dikes around a facility. Another option (Urfer 2013) would be to relocate key elements, such as major electrical equipment, to a higher elevation within the treatment plant. This would help to minimize the time a plant might be out of service as a result of flooding. Obviously, the main treated water supply conduits must also be secure.

A recent example of the impact of an extreme weather event was the extreme flooding that took place in the city of Calgary, Canada in July 2013 (Calgary Herald 2013). Although the city's two surface water treatment plants continued to function, one of the major wastewater treatment plants was out of commission for a period of some days because of the flooding. Relocating wastewater treatment plants to higher ground is probably much more difficult than doing it for drinking water treatment plants.

8.5 Some Thoughts on the Future Evolution of Water Treatment

Although many drinking water treatment processes (e.g. sand filtration) have been in use for a number of decades, there have been several major innovations in treatment over the past 30 years. The two that come most easily to mind are the gradual replacement of chlorination by UV for disinfection (Huck and Sozański 2011), and the use of membranes, most commonly either for desalination or as a replacement for granular media filtration (Huck and Sozański 2011). Although it is possible that one or two new technologies may have made significant inroads in 30 years' time, the conservative nature of the industry and the good contributions made by these two newer processes suggests that they may continue to play an important role and indicates that we may not see major paradigm shifts in treatment for the next several decades.

In considering treatment, it is important to think about why we do it. Basically, treatment is put in place to remove substances from the raw water that are present in excess of finished water regulations or guidelines, or to improve the microbiological, chemical or physical character of the water that is ultimately consumed.

Sozański and Huck (2007) and Huck and Sozański (2011) have identified seven goals for treatment. These may be stated as follows:

1. Removal of particles (including the physical removal of pathogenic micro-organisms)
2. Reduction in total organic carbon (TOC) concentrations
3. Disinfection/inactivation of pathogenic micro-organisms
4. Maximizing the biological stability of the treated water
5. Removal of chemical contaminants
6. Maximizing the chemical stability of the treated water
7. Maintaining aesthetic quality of the water reaching the consumer's tap

In terms of immediate public health risks, making sure that disinfection/inactivation of pathogens is adequate is arguably the most important of the treatment goals. The removal of particles applies essentially to surface-water supplies and is important for practical as well as aesthetic reasons. Reducing the TOC concentration is important for several reasons, of which the most important is the reduction in the concentrations of by-products that may be formed when chlorine or other disinfectants are added to achieve goal #3. It is obviously important that chemical contaminants be removed if they are present above regulatory limits. The biological stability of the treated water is important to minimize issues such as bacterial regrowth in the distribution system. The chemical stability of the water is important to minimize corrosion or precipitation reactions that may occur in the distribution system. (In addition, pH should remain stable in an appropriate range since, for example, a reduction in pH can lead to the release of lead.) Achieving the seventh goal involves removing taste-causing or odorous substances during treatment. In addition, maximizing the treated water's biological stability assists in minimizing the development of taste or odours in the distribution system.

To this could be added an eighth goal, that of reducing total dissolved solids (i.e. salt) content in cases where the raw water is seawater or brackish water. Although one or two new goals may be added in the coming decades, it is expected that those listed will remain important.

Various treatment processes can be used to address these goals, as indicated in Table 8.1. Huck and Sozański (2011) have also discussed where each of these goals is usually met in a typical treatment train (e.g. early or late in the overall train), and the fact that some goals are often addressed by more than one process, and some processes can contribute to achieving more than one goal. The fact that more than one process can address a particular goal contributes to treatment robustness.

It is impossible to predict individual technological developments in treatment. Sometimes unexpected factors can play a role. For example, one factor that led to the relatively rapid introduction of the use of UV for disinfection/inactivation was that a change in the method of assessing the effectiveness of UV against oocysts showed that much lower doses than had historically been considered could be effective. However, there are some current trends in treatment that can be expected to continue:

- A reduction in chemical usage—this tends to favour membranes now, but that may not be the case in several decades.
- A reduction in carbon footprint—i.e. "green" technologies are favoured.
- Simple and secure (i.e. robust) treatment—again this tends to favour membrane processes now.
- The use of "nano"-based processes such as adsorbents and oxidants to remove specific contaminants.
- Additional process optimization related to the development of improved "real-time" monitoring.

With respect to new treatment processes, the unit cost is very important, as indicated earlier. For example, the writer, living in Waterloo, Canada pays approximately \$1.50 (CDN) per cubic meter for water (wastewater is charged separately). There are a number of components of this price: the treatment, transportation and delivery and the entire organizational and administrative system that supports it. Although some reduction in consumption and increase in unit price can and will inevitably occur in many locations, it is thus evident that a treatment process that costs more than a few cents per cubic meter will simply not be economically viable. (This could change if only a portion of the water has to undergo certain treatments, as discussed later in the next section.)

Table 8.1 Treatment Goals and Processes

	Goal						
Process	Particle removal[a]	TOC removal	Disinfection/ inactivation	Removal of chemical contaminants	Biological stability	Chemical stability	Esthetic quality
Coagulation/ flocculation	•	(•)[b]					
Sedimentation	•	(•)					
Flotation	•	(•)					
Rapid granular filtration	•	(•)			(•)		
Biological filtration	(•)	•			•		(•)
Membranes (MF or UF)	•	(•)	•				
Membranes (NF)		•	•	•			
Disinfection/ oxidation[c]							
Chlorine	(•)		•	(•)			(•)
Ozone	(•)	(•)	•	•			
UV			•	(•)			
Ozone/UV or H_2O_2/UV		(•)	(•)	•			•
Adsorption		(•)		•			•
Air stripping				•	•		•
Ion exchange (including MIEX®)		•		•			
Secondary disinfection[d]					•		
pH correction						•	

Source Huck and Sozański (2011). Reprinted with permission
[a]Including physical removal of pathogens
[b]Not necessarily the principal goal of this process
[c]When used as oxidant, may also provide (some) disinfection
[d]Provision of residual for distribution system

8.6 The Evolving Nature of Distribution

The distribution system is arguably the least robust component of the entire water supply system. It has been said, tongue-in-cheek, that the distribution system is a large, complex reactor whose sole purpose is to degrade water quality. Obviously, this is an exaggeration, but it underscores the point that water quality does not improve as it goes through the distribution system, and the best we can hope for is that it does not degrade.

Except for aboveground storage tanks or reservoirs, the distribution system consists of buried infrastructure. In a given municipality, it has typically evolved over a number of decades as the municipality has expanded. This, plus the constantly varying demands in different parts of the system over the course of the day leads to a system that is never completely at steady state and whose hydraulic behaviour can be very complex. In addition, the different types of pipes and construction approaches used over the decades means that water traveling through the system is exposed to a number of different materials of varying ages. Although water utilities typically attempt to replace and upgrade a portion of this aging underground infrastructure every year, the substantial cost involved make this a very slow process.

Originally, distribution systems were designed with only hydraulic considerations in mind and obviously this remains an important function. Certainly the provision of adequate flow for fire protection is one of the key requirements of a distribution system. However one consequence of the historic design approach is that water can remain in some parts of the system (e.g. in “dead ends”) for extended periods of time. It has been more recently recognized that the resulting elevated “water age” can be a significant contributing factor to degradation in water quality (e.g. USEPA 2002). Interactions with the various pipe materials, that can result in corrosion and biofilm growth, can also contribute to quality degradation.

It is evident that the distribution system functions as a reactor, whether we wish it to or not. From a water quality point of view, it is thus important that it be as inefficient a reactor as possible. Materials of construction are important and Huck and Gagnon (2004) have noted the importance of pipe diameter (i.e. surface to volume ratio). Minimizing the efficiency of the distribution system as a reactor depends largely on having the water leaving the treatment plant as chemically and biologically stable as possible. This is the reason for the importance of those two previously identified treatment goals.

It is reasonable to expect that there will be significant changes in the management of distribution systems in the coming decades. The main drivers for this will be the increasing development of in-situ sensors such as “lab on a chip” devices, coupled with the already existing ability to transmit wirelessly information from those sensors to a central monitoring location. This will allow monitoring of key water quality parameters in real-time and the ability to intervene quickly if a problem is detected. This will be a measurable improvement over the current practice of routinely sampling defined points in a distribution system, and only being able to react when results (e.g. from microbiological testing) are received at some later time, and will enhance overall system robustness.

Real-time monitoring of key parameters may also allow us to reduce the emphasis on maintaining a disinfectant residual throughout the system, without reducing the protection of public health. In many parts of the world, the maintenance of such a residual is currently a regulatory requirement, although this is not the case in, for example, the Netherlands.

It is reasonable to expect that we will see further development of dual distribution systems as discussed by Huck and Sozański (2011). This will be linked to decentralized treatment.

Historically, treatment has typically taken place at a centralized location close to the source, with treated water being distributed throughout the service area. As communities have expanded, the distribution system has necessarily increased in size, leading in many cases to increased water age. This, coupled with stricter finished water quality regulations, has increased the possibility of quality issues arising in the distribution system.

In principle, a number of the issues relating the distribution system water quality and security could be addressed by providing a basic level of treatment at a centralized facility, and a second level of treatment closer to the point of consumption. In fact, this second level of treatment could be applied only to water used for or directly related to human consumption. This would of course require a second distribution system, and in practice is likely only going to be considered in new developments. This approach is distinct from point-of-entry treatment, which is sometimes used currently, particularly in smaller systems.

The water given basic treatment at the centralized facility would need to be, at a minimum, microbiologically safe, to guard against infection from accidental consumption. However it would not need to be treated to meet all water quality requirements. This water, that is not directly associated with consumption, can be used for a number of purposes including:

- toilet flushing and clothes washing
- washing of vehicles, watering lawns and gardens
- some commercial and light industrial uses
- public spaces—fountains, golf courses, etc.

If there were a second distribution system to provide water only directly related to human consumption, this would open the door to potentially more effective although costly treatment processes, because the volume being treated would be much less.

Historically, small systems have presented the greatest challenges, related often to poorer raw water quality, the lack of economies of scale, and a smaller organizational structure that makes it difficult to provide the level of support present in larger systems. However smaller treatment facilities operated within the context of a larger system would not present these difficulties. Further, the use of newer technologies such as membranes and UV disinfection/inactivation are more amenable to remote operation, thus avoiding the need to staff a number of smaller facilities. These processes are less chemically intensive than traditional ones, also removing one of the arguments for a centralized facility, i.e. that related to chemical delivery and handling.

A major advantage of such decentralized systems is that they reduce to a large extent the issue of distribution system water quality, and thus enhance the overall robustness of the water supply system. This is a significant plus.

Water reuse is not discussed in detail herein for reasons of space. However, indirect reuse is already a fact in many parts of the world, the Rhine River being a prime example of this. The issues to be overcome in implementing reuse are mainly those of public perception and acceptance, rather than technical ones. Legal issues and liability can also be important—these are surely the reason that the sign shown in Fig. 8.3 was put in place. Certainly non-potable reuse will face

Fig. 8.3 A photo taken several years ago in the airport in Adelaide, Australia

fewer hurdles than reuse for potable purposes, and this will be an additional factor leading to the use of dual distribution systems.

8.7 Concluding Remarks

As with any other matter, many of the details relating to the provision of public water supply in developed countries 30–35 years from now cannot be predicted. This is evident by comparing the world in 1980 to what it is today. However the provision of a safe and reliable water supply will remain crucial. In this regard, the five elements mentioned earlier (source, treatment, distribution, monitoring and response) and the three aspects of these (physical/technical, human and organizational) will remain important. It is likely however that the trend towards less direct intervention by humans in operational matters will continue. Robust systems will be required that protect public health and are accepted by the population. In this regard, the aesthetic quality of the finished water will invariably increase in importance.

It is likely that the distribution system and problems generated by severe weather events will present the greatest challenges over the next several decades. There will be reduced demand, greater and more deliberate reuse, and at least a partial introduction of dual distribution systems—one for the distribution of the relatively small amount of water directly associated with human consumption and the other for the rest of the supply. Inevitably, we will reduce the proportion of water used simply for “flushing”—the increasing appearance of waterless urinals in men’s washrooms is one indication of this.

In addition to these relatively technical aspects, the “soft” side of the water supply system will change. The public will demand/have access to more information and be more involved in decisions regarding the water supply system. It is quite possible that everything will move faster.

The privatization of water supply systems can be a sensitive topic. At least some additional privatization is likely, particularly in the form of public-private partnerships. We may have completely different regulatory paradigms that will influence how systems are designed and operated—we may move away from the current regulatory approach in which specific numerical values are specified for a number of different contaminants. This in turn would have an impact on how systems are designed, managed and operated.

Getting to the future successfully will require a number of things. Most importantly, society will have to find a way to ensure that the necessary funding is available to build and maintain adequate and robust drinking water supply systems. In addition, an educated and committed workforce at all levels will be even more important than today. We will have to make sure that we can undertake the appropriate proactive measures such as making site-specific plans to deal with the effects of climate change. We will need to be aware of the broader social context and how information and other factors are changing water consumers and their expectations.

Finally, we should prepare to be surprised, hopefully at least in part pleasantly.

Acknowledgments The author would like to acknowledge helpful discussions with various individuals, and in particular to mention William B. Anderson. James Merritt provided helpful review comments, and the author would also like to thank the reviewers selected by the editor. Dana Herriman provided assistance with final manuscript preparation. The Industrial Research Chair that the author leads is supported jointly by the Chair's partners (www.civil.uwaterloo.ca/watertreatment) and by the Natural Sciences and Engineering Research Council of Canada (NSERC).

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Chapter 9
The Keystone XL Pipeline Dispute Over Transferring Bitumen from the Alberta Oil Sands to US Refineries

Sevda Payganeh, Amer Obeidi and Keith W. Hipel

Abstract A strategic investigation is carried out for the conflict arising over the construction of the Keystone XL pipeline to transfer unrefined bitumen from the Alberta oil sands in Canada to refineries located in the Southern part of the United States. Through categorizing the different aspects of this conflict into environmental (e.g. threats to water resources such as Ogallala Aquifer), political, and economic dimensions, this crucial real-world conflict can be better understood and more realistically investigated. In this study, decision makers are divided (based on their authority to decide over the destiny of the project) into two groups, main and influential. Then, based on real world events, occasions, and relationships, their current situations, future options, and preferences are identified. Using the knowledge developed in this process and through the use of the Graph Model for Conflict Resolution technique, the aforementioned pipeline conflict is formally modeled and analyzed to gain strategic insights into its resolution.

Keywords Keystone XL pipeline project · Oil sands · Graph model for conflict resolution

9.1 Introduction

The Keystone XL pipeline was first proposed by TransCanada Corporation in 2008 to transfer crude bitumen from the oil sand fields in northern Alberta, Canada, to the oil refineries in the southern part of the United States (US). As

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_9

shown in Fig. 9.1, this pipeline passes through six US states—Montana, Nebraska, Oklahoma, South Dakota, Kansas and Texas—and is almost 1,980 miles in length (TransCanada 2012). Approximately 830,000 barrels of crude oil a day would be carried from the oil sands of Alberta through the Keystone XL pipeline to the Gulf Coast of the US (Parfomak et al. 2011).

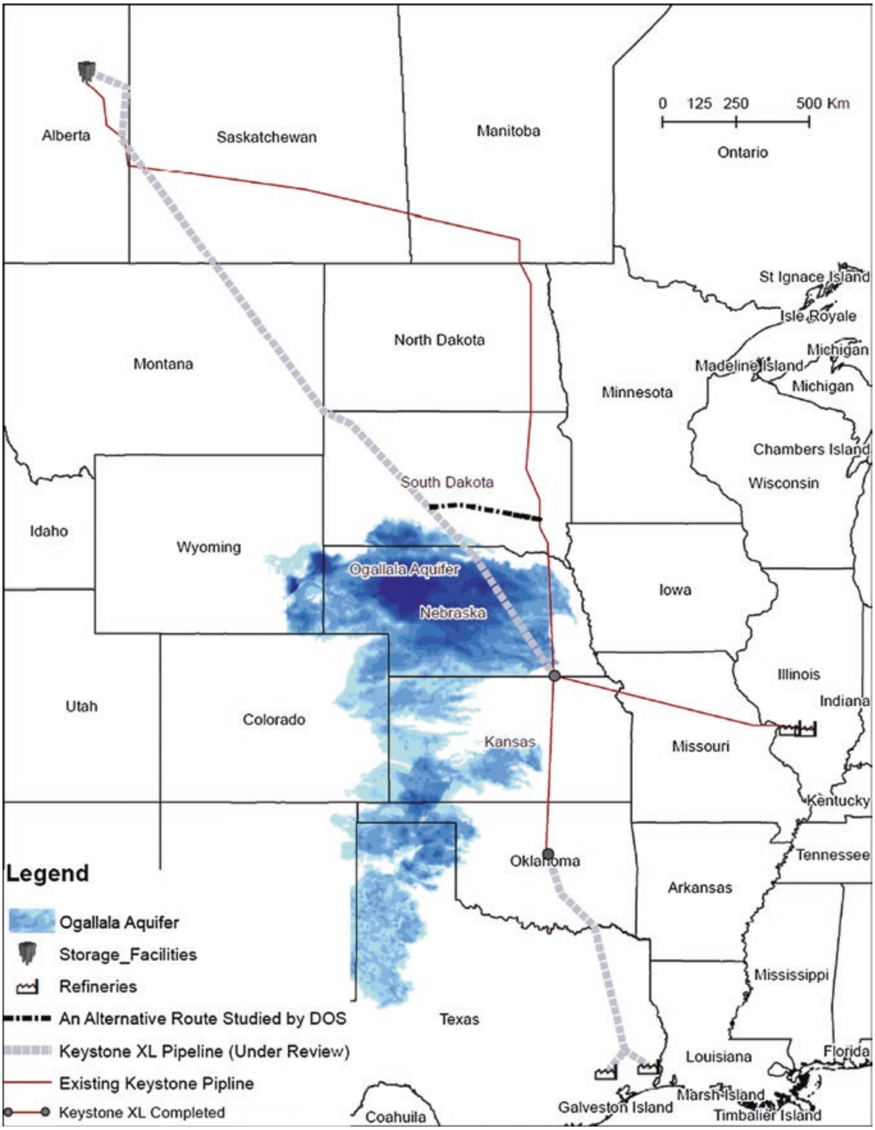

Fig. 9.1 Proposed routes by TransCanada based on TransCanada (2012)

Complexity and controversial dimensions of the project contributed to high levels of political tension between environmentalists and supporters of the construction of the pipeline. In addition to the environmental aspects, other issues such as political and economic challenges have contributed to turning this highly charged tension into a struggle for TransCanada. Usually, the word "conflict" in this context refers to serious challenges among Decision Makers (DMs) that, in extreme cases, could potentially escalate into a disastrous war. However, the current tension arising over the Keystone XL pipeline project is solely a complicated dispute, which reflects a unique form of struggle and can be referred to as a "strategic conflict."

After exploring key factors underlying this strategic conflict, the Keystone XL pipeline dispute is modeled and analyzed using the graph model for conflict resolution technique (Fraser and Hipel 1984). It is hoped that a systematic investigation of the conflict furnishes a better understanding of the dispute, how it can be more effectively managed, and other valuable strategic insights. Application of the conducted study in the real word, conclusion, and insights are provided to demonstrate the efficiency of utilizing the graph model.

9.2 Challenges Raised in the Strategic Conflict

The following framework is proposed to study the reasons and context regarding the causes and consequences of this costly dispute. This study examines three interrelated dimensions consisting of (1) environmental (2) political, and (3) economic factors which underlie this controversy. This background investigation allows one to better appreciate key issues underlying the pipeline conflict and to construct a sensible conflict model of the situation as is done in Sect. 9.3.

9.2.1 Environmental Dimension

Increasing trends of human development in technological and industrial sectors have greatly raised dependency on oil resources. Although efforts to reduce our dependency on fossil fuel, and replace conventional energy sources with renewable ones, such as water, wind, solar, and nuclear sources, have been initiated, oil and similar fossil sources of energy still play a critical role in the world. The dependency of the economy on energy hugely increases the importance of cheap production and distribution of oil worldwide. Limitations in the availability of energy sources and, more significantly, serious environmental concerns reinforced more restrictions on producing and using oil and crude oil sands. However, a sustainable point of view necessitates that industries' leaders consider addressing environmental impacts as well, rather than focusing on solely economic profits.

Despite TransCanada's endeavors to achieve the consent of opponents, current events on the ground have shown that the Keystone XL project has the potential to create serious environmental impacts (O'Rourke 2013; Parker 2013). Sections of the pipeline in the Sand Hills region of Nebraska pass through the Ogallala Aquifer. This aquifer is the largest aquifer in the world with an approximate area of 450,000 km^2 expanding through eight states (South Dakota, Nebraska, Wyoming, Colorado, Kansas, Oklahoma, New Mexico, and Texas). Moreover, the Sand Hills region has a shallow groundwater, a high concentration of wetlands, and a sensitive ecosystem. The construction of the pipeline would potentially create negative consequences for this region, place further stresses on this ecosystem, and exacerbate global warming (Parfomak et al. 2011). Consequently, various environmental groups and concerned citizens, especially those who live in the Nebraska region along and in proximity to the pipeline, oppose this project (Parker 2013).

In March 2008, the US Department of State (DOS) defended TransCanada's project, stating that "it increases US market access to crude oil supplies from a stable and reliable trading partner, Canada, which is in close proximity to the United States" (Department of State 2008). However, the US National Environmental Policy Act (NEPA), stipulates that DOS should investigate and report the potential environmental consequences of the proposed Keystone XL project in an Environmental Impact Statement (EIS) before announcing the environmental impacts to the public (Parfomak et al. 2011). Also, in July 2010, the US Environmental Protection Agency (EPA) stressed that DOS should study "greenhouse-gas emissions, air pollution, pipeline safety, wetlands and migratory-bird populations" more adequately with regard to the Keystone XL project (Welsch and Newswires 2010). The EPA further pointed out that TransCanada will have to use and heat up underground water and diversions from the Athabasca River in Alberta to extract bitumen from sand. This requires large amounts of natural gas and energy. In this process, thirteen chemically dangerous elements, such as arsenic and lead, will be released into rivers and aquifers. Since tar sands include sulfur and nitrogen, this can lead to the creation of other dangerous substances, such as SO_2 (Natural Resources Defense Council 2011; Timoney and Lee 2009).

However, DOS issued an EIS report in August 2011, stating that "the pipeline would have no significant impact on the environment" (Zeller Jr 2011). This statement ignited several protests in Washington, when more than 500 protesters gathered in front of the White House demanding that President Obama reject TransCanada's proposal (Gerken 2011).

All in all, the US needs to secure its energy resource supply. It has no choice other than to buy crude oil from Canada or from other regions including the Middle East. However, the US considerably prefers to deal with Canada as its neighboring friend and ally. On the other hand, because of worldwide pressure and regulations regarding promoting environmentally sustainable industries, the US and Canada are trying to find ways to address environmental issues in such processes as discovering, extracting and transporting energy products. Through collaborative work by the federal and provincial governments, Canada seeks new technologies to combat any negative environmental impacts of the Keystone XL pipeline and to gain sustainable resolutions. Nevertheless, other aspects, including politics and economic concerns, intensify the complexity of the strategic conflict.

9.2.2 Political Dimension

The destiny of the Keystone XL project has become a subject of conflict at the US national level between the Democratic and Republican Parties. One main cause of the dispute is that the Keystone XL is considered an international project. Regulations require that, for the project to be approved, a presidential permit must be issued and announced by DOS. This process requires a comprehensive investigation regarding various aspects of the project to satisfy US "national interest" (Parfomak et al. 2011).

One of the tipping points of the conflict emerged when President Obama rejected TransCanada's proposal on January 18, 2012. DOS stated that Republicans were trying to pass legislation to force the President to render a decision on the project within 60 days. Although there were no doubts about the economic benefits of operating the pipeline, it is suspected that the Republicans' prime objective was to use this project to pressure the Democrats during the November 2012 presidential election (Cohen 2012). President Obama expressed his disappointment regarding Congressional Republicans who pressured him to make such a decision (Argitis and Loon 2012). Although President Obama rejected the project, he kept his support regarding the project, indirectly requesting modification from TransCanada (O'Rourke 2013). For example, in the same statement, he mentioned that: "we will continue to look for new ways to partner with the oil and gas industry to increase our energy security" (Argitis and Loon 2012).

By avoiding the Sand Hills of Nebraska, on May 4, 2012 TransCanada submitted an alternative route for the pipeline. This provoked numerous negative reactions. On July 17, 2012, the Nebraska Department of Environmental Quality (NDEQ) released an initial response report stating that the alternate route still goes through sandy soils, which are similar to the Sand Hills of Nebraska (Attorney 2012).

After months of investigations regarding the Keystone XL project, DOS released an EIS report on March 1, 2013, in which it stated that the project will have little impact on the environment. Subsequently, the top Republican in Congress, House of Representatives Speaker John Boehner, asserted that, after 4 years of waiting and "needless delays," it is time "to stand up for middle-class jobs and energy security and approve the Keystone pipeline" (Daly 2013).

The rejection of the Keystone XL project in January 2012 by President Obama has further complicated the relationship between Canada and the US. The Prime Minster of Canada stated that "this is clearly the biggest infrastructure project on the continent, and once the election is settled, we believe it will be approved" (Efstathiou 2012). But, he emphasized that, if the US does not approve the project this time, Canada will probably diversify its energy exports to Asia, a decision that would not favor US interests at all (ICTMN 2012; Potter 2012). Canada's announced intentions to diversify the crude oil market to the Asian markets is considered to be a leverage Canada is using to pressure the US administration to give presidential approval regarding the project (Efstathiou 2012).

9.2.3 Economic Dimension

Although extending the pipeline from Alberta to the US Gulf Coast has caused many protests by environmentalists, fishermen and aboriginal groups, it has been shown to provide an enormous business opportunity for investors, producers and developers (Canadian Academy of Engineering Energy Pathways Task Force 2012a). The Government of Canada estimates that if the Keystone XL project is approved, close to hundred thousand jobs per year will be created in the US between 2010 and 2035. With increased pipeline capacity, this number could increase by 60 %. There are huge immediate economic benefits, about 100–600 million dollars annually, that could potentially be gained as a consequence of transporting and processing oil sands in refineries located in US Gulf Coast (Hudson 2013). Exporting oil sands from Canada shortens the supply line and, thus, is economically beneficial to US.

A study conducted by the US Department of Energy Security in 2011 showed that Canada's oil sands could help eliminate US dependency on imports from other suppliers such as Venezuela and the Middle East. Amid a congressional hearing in December 2011, TransCanada's president stated that "Keystone XL will bring many benefits to the United States, but I believe the most important role that the Keystone will play is to bring energy security to the United States during what has been recently some very unsettling times overseas" (Clayton 2012).

Although the Keystone XL project seems to be economically beneficial for the US, the project's financial benefit for Canada should be investigated from both short and long-term perspectives. Canada can build pipelines to the US to ship unprocessed bitumen to under-utilized refineries to be upgraded. This will ensure quick short-term profits for oil sand companies, the Alberta Government, and Federal Government. However, if Canada tries to upgrade the bitumen in Canada, capturing "more than $60 billion per year in value-added products and commensurate to jobs in Canada," it would enjoy the long-term benefits of the Keystone XL project (Canadian Academy of Engineering Energy Pathways Task Force 2012b).

Figure 9.2 gives a historical summary of important occurrences that have provoked the strategic conflict regarding the Keystone XL project. Following the numbers on the figure step by step, the trend of the occurrences of this conflict can be better understood.

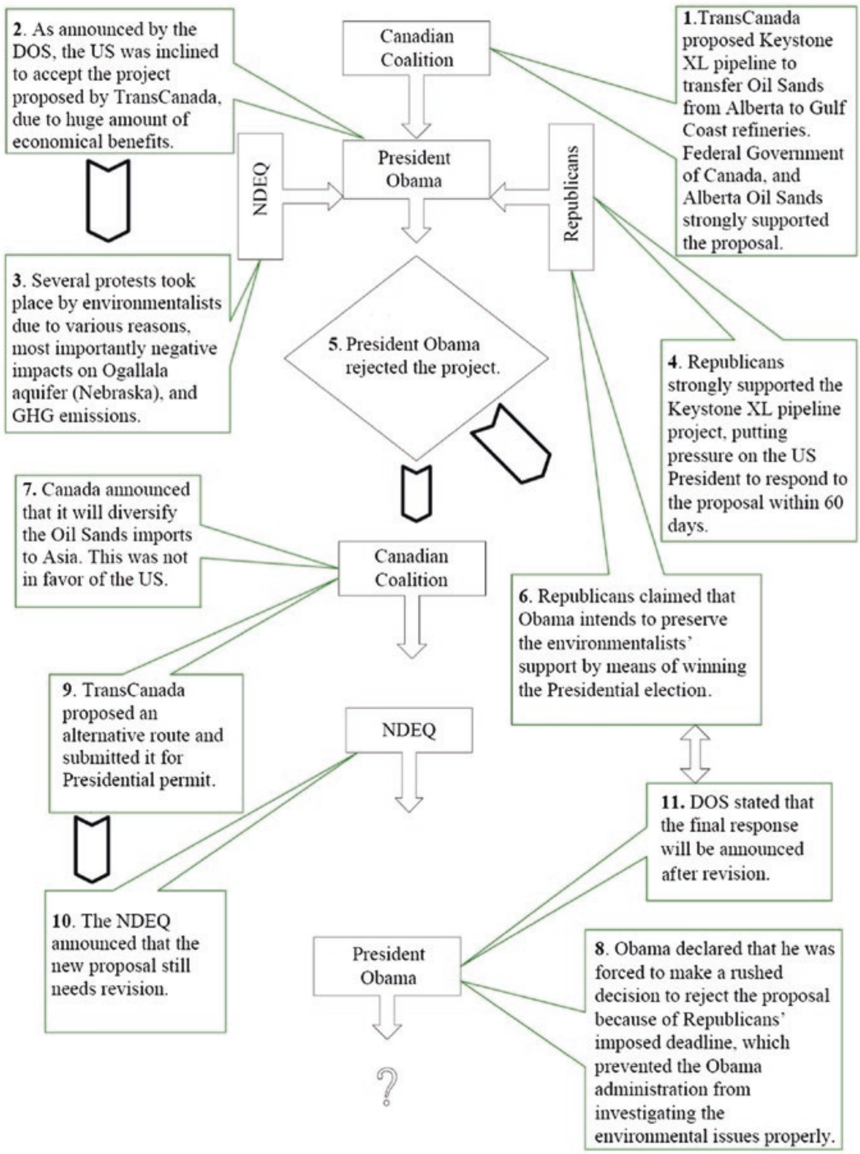

Fig. 9.2 Chronology of the Keystone XL conflict

9.3 Graph Model for Conflict Resolution

Uncertainty in the economic gains and the extent of potential environmental degradation, catalyzed by the political bickering between Republicans and Democrats, have led to brewing strategic conflict at the local and international levels in the US and Canada. The Keystone XL pipeline is being studied using the Graph Model for Conflict Resolution, introduced by Fraser and Hipel (1979). This technique is unique in providing a detailed model of he dispute among decision makers (DMs).

The graph model technique consists of two parts, modeling and analysis. In the first step, the DMs are identified. In the Keystone XL case study, DMs have been categorized as main and influential. The main DMs are those who have the authority to decide about the project. A strategy describes a DM's decision made based on the set of options of that particular DM (Fang et al. 1993). The combinations of DMs' strategies develop the states. The possible options, feasible states and unilateral transitions of each DM through the states must be constituted. DMs' preferences and outcomes are ranked from the most to the least preferred for each DM. In the second step of the graph model technique, stability analysis using logical rules called solution concepts that describe DMs' strategic interactions are applied to every outcome in the conflict model. The model used in this study was developed before the US presidential election in November 2012.

As summarized in Table 9.1, President Obama and Canadian Coalition (consisting of the Federal Government of Canada, TransCanada, and Alberta Government) are the main DMs, while Congressional Republicans and NDEQ are the influential DMs. The US and Canada are in agreement about the need and importance of constructing the pipeline. However, some significant details and circumstances, such as environmental concerns, surrounding the Ogallala aquifer and Athabasca River, and the dynamics of political rivalry during the US 2012 presidential election, are causing disagreement between these two main DMs.

Influential DMs include political parties, organizations, involved groups and states, such as the US Congress, DOS, NDEQ and Oklahoma, Kansas, Nebraska, Montana, South Dakota and Texas States. Although parties in this category have no authority to make a final decision on the project, they have the ability to influence it indirectly through lobbying and exerting political pressure on the main DMs. To develop a simpler and more sensible model, the Congressional

Table 9.1 The DMs and their options

DMs	Options
President Obama	1. Approve the Keystone XL pipeline project (approve)
	2. Request major modifications from the Canadian Coalition (major modification)
	Note When President Obama does not choose options 1 and 2, it means that he is rejecting the project
Canadian Coalition	3. Build revised project as of May 2012 (build)
	4. Accept major modifications (modify)
	Note When Canada does not choose options 3 and 4, it means that the project is canceled. Canadian Coalition may think about dealing with other customers in Asia
Republicans	5. Pressure the President to approve the project (pressure)
NDEQ	6. Pressure to stop the project, otherwise reduce and even eliminate all environmental impacts (pressure to solve or stop)

Republicans and NDEQ have been selected as representatives of the influential DMs. Republicans represent supporters of the Keystone XL pipeline project, while NDEQ represents opponents and parties who put pressure on the main DMs to resolve environmental concerns completely before granting a presidential permit.

As of September 2012, when the model was developed, there were six options for the DMs. Since an option can be chosen or not, the six options indicated in Table 9.1 produce 2^6 states which represent all combinations of options that may occur. Therefore, each state refers to a combination of decisions that could be made by the DMs. As shown in Table 9.1, each of the main DMs has two options.

For example, President Obama could approve the project as it has been proposed or with minor modifications. The other option is to request major modifications from the Canadian Coalition. Not selecting either of these options means that President Obama intends to reject the project.

9.3.1 The Set of Feasible and Infeasible States

After identifying the DMs and their options, states that are deemed impossible to materialize because of logical impediments by combination of options are called infeasible states and removed from the model (Fang et al. 1993). For example, in Table 9.1, if President Obama decides to choose his second option (i.e., Modify), TransCanada cannot start the construction (i.e., choose option 3). Consequently, options 2 and 3 cannot occur simultaneously. By systematically eliminating states that are deemed to be unreasonable or unlikely to occur, many infeasible states were dropped from the model.

Only twenty-four states are considered feasible as shown in Table 9.2. This table which is called "option form" contains information regarding options of DMs, each DM's strategy and all the developed feasible states. As shown in Table 9.2, Y means "yes", showing the situation where the option has been chosen by the DM. On the other hand, N indicates "no", which describes the situation where the option has not been selected. In the previous example regarding options 2 and 3 not happening simultaneously, it can be noted that none of the states in Table 9.2 show a "Y" for both options 2 and 3 at the same time because this situation cannot happen in the real world, and thus, is infeasible. As another example, it can be stated that if President Obama decides not to approve and not to demand a modification to the project ("N" for both options 1 and 2), he is rejecting the project altogether. Therefore, in this condition, Canada cannot start constructing the project ("Y" for option 3). This means that the states which show "N" for both options 1 and 2 and "Y" for option 3 are ruled out of the feasible states and thus, are not shown on Table 9.2. Notice that a DM can make transitions to other states while other DMs' strategies do not change. For instance, President Obama can move in the conflict model from states 5 to 6 since this transition does not require Canadian Coalition, Republicans and NDEQ to change their strategies. Some of the feasible states are transient states.

For example, state 5 and 11 are in-between states from when the project is approved by President Obama to when the construction of the pipeline started by Canadian Coalition. In Table 9.2, state 24 represents DMs' current status regarding the Keystone XL project.

9.3.2 DMs' Preferences

DMs' preferences in the conflict over feasible states are ordinally ranked from the most to the least preferred as illustrated in Table 9.3 (from left to right). Equally preferred states are indicated by a line drawn on top of the numbers. President Obama's priority is to proceed with the operation of the pipeline (i.e., choosing option one).

However, acceptance of the project could be conditional (i.e., requesting some minor modifications from TransCanada) to show some attention to environmentalists' concerns. If President Obama selects the second option, the US is not at all in favor of Canada ignoring the request and transferring oil sands to Asia.

The Republicans strongly insist that the project receives approval from the President because of many reasons, most importantly the economic benefits of the Keystone XL pipeline (O'Rourke 2013).

On the other hand, Canadian Coalition would prefer that the NDEQ become convinced that the project poses no serious danger to the environment. Yet another issue for Canadian Coalition is the need for Canada to exhibit an environmentally friendly stance to enhance its worldwide reputation. Canadian Coalition waited almost five years and proposed a new report about how to resolve the environmental impacts even after President Obama's rejection in January of 2012. Therefore, Canada's priority is for the project not be rejected again. This is why state 3, in which president Obama approves the project without any further modifications, is the most preferred situation for Canada. In state 3, the environmentalists (represented by the NDEQ) do not impose pressure on President Obama for the project to be denied and thus, the project will be approved smoothly (see Table 9.2). Or in state 9, which is the second preferred state for Canada, the project gets a go ahead by President Obama without any modifications, and under the pressure of the Republicans for the project to be approved. In contrast, according to state 16 (which has been chosen as the least preferred state for Canada), President Obama rejects the project while Canada is in the process of modifying it. This state occurs mostly because of the pressures imposed by NDEQ on President Obama.

All these preferences and states have been developed based on a comprehensive literature review of the ongoing conflict and the relationships between the stakeholders of this conflict. Therefore, the process of ranking the states and preferences is somewhat subjective and thus, can be considered as a limitation to the current research and method in general.

Table 9.2 Option form

DMs	States											
	1	2	3	4	5	6	7	8	9	10	11	12
President Obama												
1. Approve	N	N	Y	N	Y	N	N	N	Y	N	Y	N
2. Modify	N	Y	N	N	N	Y	N	Y	N	N	N	Y
Canadian Coalition												
3. Build	N	N	Y	N	N	N	N	N	Y	N	N	N
4. Modify	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y
Republicans												
5. Pressure	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
NDEQ												
6. Pressure to solve or stop	N	N	N	N	N	N	N	N	N	N	N	N
DMs	States											
	13	14	15	16	17	18	19	20	21	22	23	24
President Obama												
1. Approve	N	N	Y	N	Y	N	N	N	Y	N	Y	N
2. Modify	N	Y	N	N	N	Y	N	Y	N	N	N	Y
Canadian Coalition												
3. Build	N	N	Y	N	N	N	N	N	Y	N	N	N
4. Modify	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y
Republicans												
5. Pressure	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
NDEQ												
6. Pressure to solve or stop	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Table 9.3 Ranking of the states for DMs from most (left) to least (right) preferred

DMs	Ranking of states											
President Obama	3	5	6	15	17	18	9	11	12	21	23	24
Canadian Coalition	3	9	21	15	5	11	23	17	6	12	24	18
Republicans	9	21	3	15	11	23	5	17	12	24	6	18
NDEQ	13	16	14	19	22	20	7	10	1	4	8	2
DMs	Ranking of states											
President Obama	1	13	7	19	4	10	16	22	2	8	14	20
Canadian Coalition	8	2	20	14	17	7	19	13	10	4	22	16
Republicans	7	1	19	13	10	22	4	16	8	20	2	14
NDEQ	18	24	6	12	17	15	21	23	5	11	3	9

9.3.3 *Representing the Strategic Conflict Using the Graph Form*

Figure 9.3 illustrates the integrated graph model for the Keystone XL strategic conflict. The graph model helps one to have a better sense of DMs' movements through the feasible states. The numbers shown at the nodes refer to the feasible states presented in Table 9.2. The arcs represent state transitions for each DM's unilateral moves from one state to another, which occur when a particular DM makes a selection from the options it controls. In reality, when transitioning from one node to the other, the DMs consider their preferences and tend to move to more favorable states. These transitions are called unilateral improvements (UIs).

According to Fig. 9.3, President Obama could have a transition from state 18 to state 17, which reflects the DMs' preference of state 17. After the transition to

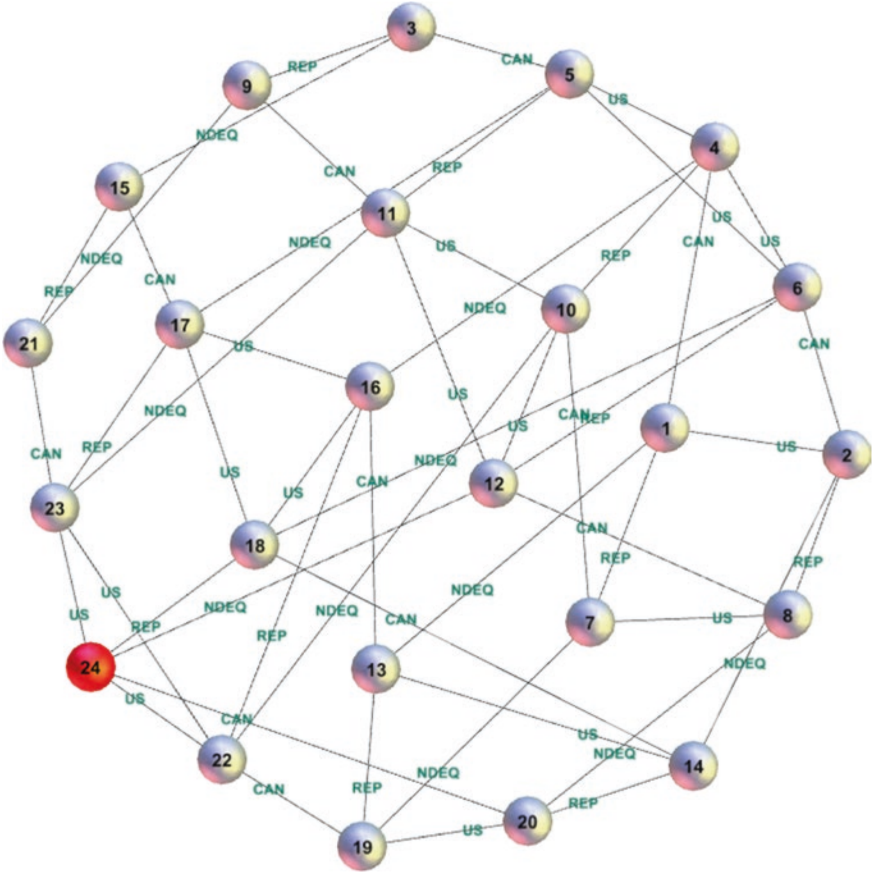

Fig. 9.3 Integrated graph form; *Note* The relations between the arcs are all bidirectional

Table 9.4 President Obama's possible movements based on Fig. 9.3

	State numbers											
Possible movements	1	3	4	7	9	10	13	15	16	19	21	22
	2		5	8		11	14		17	20		23
			6			12			18			24

state 17, Canadian Coalition could move to state 15, while, Republicans would prefer to progress from state 15 to state 21.

Since at state 21 none of the DMs can improve to a more preferred state, this state is stable for all the DMs. But state 21 is less preferred for President Obama than the original state, state 18. Thus, the improvement of President Obama from state 18 to 17 could eventually put him in a worse situation (state 21). According to a definition in graph model technique, states like 18 are called sequentially sanctioned for a particular DM. Although in some instances, a DM can make transitions to more preferred states in the initial steps, it is better not to move from these sequentially sanctioned states since the DM ends up in a worse situation. In this case, state 18 is sequentially sanctioned for President Obama.

Table 9.4 shows President Obama's possible movements. For instance, he can move unilaterally between states 11 and 12, because he can change his decision from demanding a modification to approving the project, or vice versa (in an extreme but possible scenario), independent of all the other DMs' strategies.

This means that a movement from state 11 to 12 does not require any of the other DMs, except President Obama, to change their decision regarding the conflict. However, as mentioned previously, state 12 is less preferred to President Obama compared to state 11 because he can approve the project without having to go into the process of modification again. Therefore, he prefers to unilaterally improve from state 12 to state 11 and not the other way around.

9.3.4 Stability Analysis of the Keystone XL Strategic Conflict

Solution concepts are a set of rules for modeling moves and countermoves of DMs in the conflict. They describe possible human behaviors during conflict. For instance, according to Table 9.3 and Nash stability's definition in Table 9.5, it is

Table 9.5 Solution concepts (Fraser and Hipel 1984)

Solution concepts	Stability description
Nash stability (R)	A focal DM cannot unilaterally move to a more preferred state
General metarationality (GMR)	All of the focal DM's unilateral improvements are sanctioned by subsequent unilateral moves by others
Symmetric metarationality (SMR)	All of the focal DM's unilateral improvements are still sanctioned even after a possible response by this DM
Sequential stability (SEQ)	All of the focal DM's unilateral improvements are sanctioned by subsequent unilateral improvements by others

preferred and rational for Republicans to stay at state 9 since there are no other more preferred states for them to move to unilaterally. In this state, the project is approved by President Obama under the pressure imposed by the Republicans, with no pressure from the environmentalists to stop the approval process. As another example, state 7 is more preferred to state 8 for President Obama. This is because President Obama prefers not to be in a situation in which he demands modification of the project, but Canada turns to Asian markets, avoiding a modification of the project's construction proposal. Thus, based on Table 9.3 and Nash stability, it is rational for President Obama to stay at state 7 rather than to unilaterally move to state 8. Or in the case of sequentially sanctioned (SEQ) states, if the focal DM unilaterally improves to a more preferred state, other DMs' unilateral movements from that state result in a less preferred state for the focal DM than the initial state it was in before moving. For example, if President Obama decides to approve the project after having demanded a modification (unilaterally improves from state 12 to 11), Canada will start constructing the project (unilaterally improves from state 11 to 9). Then, NDEQ prefers to unilaterally improve to state 21 which represents a situation in which it pressures the stakeholders to stop the project or at least to modify the project before it goes further. But based on Table 9.3, state 21 is less preferred for President Obama than state 12 and thus, President Obama tends to stay at this state rather than move to state 11 which consequently results to state 21 which is a less preferred state than state 12. Therefore, state 12 is a SEQ for President Obama. Analyzing the equilibrium states based on the solution concepts is easier with GMCRII (Fang et al. 1993), a decision support system, rather than evaluating the states manually.

After identifying the stability of individual states for each DM, equilibrium states (states that are stable for all the DMs developing an overall stability) are identified. Table 9.6 lists the results of the stability analysis of the Keystone XL strategic conflict using the GMCRII decision support system which reveals that states 19 and 21 are stable for all DMs under all solution concepts. Other states are stable under some but not all solution concepts for some of the DMs.

States 19 and 21 represent enforcement from influential DMs. Republicans try to push President Obama to move toward approving the project, while the NDEQ insists that the environmental concerns should be solved before granting an approval for the project. State 19 indicates that President Obama rejects the project under pressure from the NDEQ, and Canada stops insisting on the agreement. Therefore, Asia becomes Canada's main customer (O'Rourke 2013). In state 21, however, the US directly accepts the proposal and becomes Canada's main

Table 9.6 Stability analysis

	States		
Solution concepts	12	19	21
Nash		✓	✓
GMR	✓	✓	✓
SMR	✓	✓	✓
SEQ	✓	✓	✓

customer. However, there is the possibility of requesting some minor modifications while accepting the project. State 12 is considered an acceptable result and relatively strong equilibrium because it satisfies the rules of all solution concepts except Nash stability.

9.3.5 Status Quo Analysis for State 21

The status quo, state 24 in Table 9.7, represents the current real world situation. Other feasible states show likelihoods of DMs' movements from the status quo. Table 9.7 shows transition of DMs from status quo to state 21 which is one of the equilibrium states. As described in Table 9.7, if the President improves from status quo to state 23, the Canadian Coalition progresses to state 21, which is an equilibrium state for all DMs. In the Keystone XL case, state 23 is considered as a transient state. Table 9.8 shows each DM's point of view regarding the project when they are in state 21.

Table 9.9 shows the transition of DMs from the status quo to state 19. If the President makes a transition from status quo, state 24, to state 22, the Canadian Coalition could progress to state 19, which is an equilibrium state for all DMs. In

Table 9.7 State transition to state 21, an equilibrium state

DM	Option	Status Quo		Transient State		Possible Equilibrium State
President Obama	1	N	→	Y		Y
	2	Y		N		N
Canadian Coalition	3	N		N	→	Y
	4	Y		Y		N
Republicans	5	Y		Y		Y
NDEQ	6	Y		Y		Y
State Number	-	24		23		21

Table 9.8 Description of DMs' points of view in state 21

DMs	Point of view in state 21
President Obama	Approves the proposal while requesting minor modifications to show his appreciation of environmentalists
Canadian Coalition	Starts building the Keystone XL pipeline proposed by TransCanada in April 2012, while using other customers (e.g. China) as leverage for economic bargaining with the US
Republicans	Tries to find ways to show that the decision of Democrats is solely a political game (wasted time by initially rejecting the project to help Obama win the 2012 election), and thus, continue pressuring the President
NDEQ	Not satisfied with the result; therefore, keep pressuring

Table 9.9 State transition to state 19, an equilibrium state

DM	Option	Status Quo	Transient State	Possible Equilibrium State
President Obama	1	N	N	N
	2	Y	N	N
Canadian Coalition	3	N	N	N
	4	Y	Y	N
Republicans	5	Y	Y	Y
NDEQ	6	Y	Y	Y
State Number	-	24	22	19

Table 9.10 Description of DMs' points of view in state 19

DMs	Point of view in state 19
President Obama	Rejects the proposal due to pressure from NDEQ
Canadian Coalition	Cancels the Project and refuses to insist. There is even a likelihood that it decides to diversify its crude oil to Asia
Republicans	As supporters of the project, they are not satisfied with the results and therefore their pressuring would continue
NDEQ	Are satisfied with the results, since their pressuring had an influential role on President Obama to reject the project

the Keystone XL case, state 22 is considered a transient state. Table 9.10 briefly describes DMs' points of view in state 19. If President Obama rejects the proposal proposed by TransCanada in May 2012, Canadian Coalition would prefer to cancel the project. In this situation, unlike NDEQ, the Republicans would not be satisfied with the results and continue their pressuring.

If President Obama requests modification, Canadian Coalition may refuse to modify the project for applying again. This further complicates the situation for President Obama since it is not preferable for him to be denied by Canadian Coalition. Therefore, he is better off to either approve or completely reject the project. However, due to many factors such as economic benefits, meeting national interests (Gasser 2012; O'Rourke 2013), and allowing less dependency on importing oil from the Middle East, the likelihood of President Obama approving the project is high and occurrence of state 21 is higher in comparison to state 19.

9.4 Strategic Insights of the Keystone XL Pipeline Dispute

The purpose of this systematic analysis is to carry out a formal study of the Keystone XL pipeline dispute to gain a better understanding and strategic insights. The insights drawn from the study with the assistance of the graph model technique shows the credibility of a wide range of capabilities of this technique. The DMs' options, and wants have been analyzed in light of in-depth insights regarding the strategic conflict. The Keystone XL project model further helps the DMs to analyze the strategic conflict and to predict other DMs' movements and strategies. For example, the analysis reveals that the initial rejection of the project by President Obama could be considered a wise decision. Although the likelihood of diversifying Canada's oil sands to other markets is high, President Obama knew that the Canadian Coalition is aware of the many environmental impacts of the first proposed Keystone XL pipeline (Gasser 2012). Consequently, in May of 2012, TransCanada applied again for a Presidential Permit for a rerouted Keystone XL pipeline project. To preserve environmentalist support, President Obama also managed to defer a decision on the project to after the presidential election of 2012. On the other hand, the Republicans were aware of the reasons behind this decision and thus continued pressuring President Obama.

One of the important contributions of applying the graph model technique to the Keystone XL project is to understand the dynamic complexity of multi-participant, multi objective decision making process, and the importance of timing. The model not only gives an understanding of the situation at a single point in time, but it can also effectively provide quick support to policy and governance by being revised based on new circumstances to determine the strategic implications. For instance, after Canada's decision to diversify oil sands to China, rankings of DMs' preferences changed in the proposed model. Requesting modification had been a high priority for US, but after the initial rejection of the proposal by President Obama, when Canada announced multiple times that it would diversify its oil to regions such as Asia, the risk of possible negative outcomes of modification increased in US's point of view. Thus, US's preference rankings altered. This change in preferences can be effectively addressed through the graph model technique.

The projected economic benefits of the Keystone XL conflict are in contradiction with the environmental preservation that the world currently needs. Using the graph model technique, the current analysis aims to study and provide a wise balance between these two sides. Therefore, in addition to facilitating communication and cooperation among DMs, the quality of understanding, negotiation and mediation among them would be enhanced. This enables a variety of groups, most importantly managers, to better understand and make decisions regarding operation and leadership of their organizations towards higher efficiency and productivity. In turn, with this systematic approach, environmental aspects can also be addressed through a more sustainable manner.

The other insightful conclusion the graph model technique sheds light on is that a short-term perspective towards decision making might not be an ideal strategy for maximum gains. For example, in the case of sequentially sanctioned states for a particular DM, although a DM makes a transition to a higher preferred state in the first move, in the long run, the conflict will end up in a less preferred equilibrium state for that DM. The graph model technique gives a unique opportunity to DMs to foresee different consequences of their decisions and to take appropriate action towards attaining long-term profits instead of short-term and temporary accomplishments.

9.5 Conclusion

Exporting bitumen from the oil sands in Canada through the Keystone XL pipeline is a controversial topic between Canada and the US. Considering the different aspects of this conflict categorized into environmental, political, and economic dimensions, this crucial real-world issue is systematically studied. Although the environmental issues of the project are increasingly important, current technologies limit TransCanada from proposing and conducting a completely environment-friendly project. On the other hand, the huge financial profits of such projects for Canada motivate it to support attempts at proposing and conducting them. Therefore, the Canadian Coalition, including its industry, provincial governments, and also TransCanada, have made multiple attempts to diminish the environmental effects of such projects to be able to gain maximum economic profits and produce minimum ill effects on the environment.

The graph model for conflict resolution technique helps to investigate all of the details required for decision making in the real world. A strategic investigation to identify key factors—DMs, their options, preferences, feasible states, and transitions to more preferred states—was conducted to structure the model. Then, a stability analysis ascertained the potential equilibrium states or resolutions, which are stable states for all DMs.

This study is an attempt to address the complexities underlying the Keystone XL pipeline project. Decisions of the different stakeholders playing a role in the project have been investigated, depicting an in-depth view of the situation surrounding this project. Through assessing various dimensions of this controversial project, its effects on the environment and the economies of the two neighboring countries of Canada and US have been discussed.

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Part III
Consensus-building, Bargaining, and Negotiations

Chapter 10
A Data Mining Tool for Planning Sanitary Sewer Condition Inspection

Richard Harvey and Edward McBean

Abstract The deterioration of aging sanitary sewer pipes poses a potentially significant environmental and economic threat. While accurate information on sewer condition required for proactive management can be obtained through closed-circuit television (CCTV) inspections, these inspections are expensive and hence frequently limited to relatively small portions of the sewer system. Hence, there is real value in alternatives to assist in determining sewer integrity. Data mining is demonstrated as a means of extracting information from limited inspection records, allowing sewer pipe condition to be predicted for pipes that have not yet been inspected. The paper describes a classification tree algorithm capable of providing insight into a pipe condition dataset obtained after inspecting a portion of the sanitary sewers in Guelph, Ontario, Canada. The model is developed with minimal data pre-processing effort and illustrates the influence of pipe-specific attributes (e.g. year of construction, diameter and length) on pipe condition in a format that can be easily shared with those unfamiliar with the data mining process. The predictive capability of the classification tree is validated using a stratified test set representative of the distribution of pipe condition existing in the sewer system. CCTV inspection datasets are often imbalanced—with significantly more pipes in one condition class than another and this is problematic as data mining algorithms tend to be most effective when observations available for model development are balanced across classes. An optimally tuned classification tree predicts binary pipe condition (*good* vs. *poor* condition) with an overall accuracy of 76 % (282 out of 364 instances of pipe condition correctly predicted in the stratified test set). The model achieved an acceptable test set area under the receiver operating characteristic (ROC) curve of 0.77 and can effectively identify individual pipes for future

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_10

rounds of inspection. The data mining approach presented herein is found capable of unlocking information contained within inspection records and enhances existing management practices used in the wastewater industry.

Keywords Data mining · Pipe condition · Sanitary sewers · Decision trees

10.1 Introduction

Approximately 800,000 miles of sewer pipe are currently in operation across the United States of America (ASCE 2013). The majority of this infrastructure is approaching the end of its useful design life and it appears decades of neglect have taken a toll on this important national capital asset. Aging sewers discharge an estimated 900 billion gallons of untreated wastewater into American waterways each year (ASCE 2013). These sewers often carry pathogenic microorganisms, industrial toxins, and endocrine disrupting compounds capable of causing immediate and long-term damage to the environment. As such, leaking sewers place decades of progress in public health and environmental protection at risk (EPA 2002).

Many municipalities rely on sewers that were installed more than 75 years ago to transport their wastewater. Pipes in these systems were initially designed to serve populations half their current size and continued population growth is expected to stress pipes beyond their design capacity and accelerate the process of pipe deterioration over time. It is expected that an investment of $390 billion will be required from 2002 to 2022 to rehabilitate defective American sewers and expand existing systems to meet increasing demand (EPA 2002).

The threat posed by deteriorating sewers is typically determined using closed-circuit television (CCTV) inspection, where a small camera mounted on a robot is driven along the length of a pipe (Fig. 10.1). Defects inside the pipe (e.g. cracks,

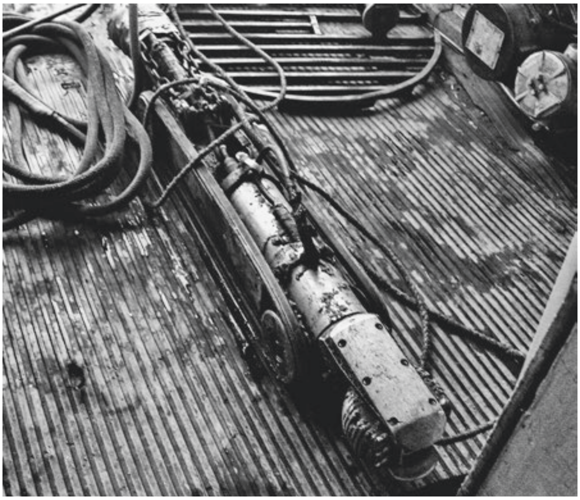

Fig. 10.1 Inspections are typically carried out using robots equipped with cameras that are inserted into a pipe and remotely operated from the road surface

fractures and collapsed sections) are identified and assessed using systems designed to minimize subjective evaluation of the camera footage. Each inspected pipe is typically assigned an ordinal grade to reflect its structural condition (e.g. 1: no defects, 2, 3, 4 or 5: collapsed or collapse imminent).

CCTV inspections are time-consuming and expensive, posing an average cost to a small municipality of $0.84 per linear foot of inspected pipe (EPA 2010). Budgetary restrictions may restrict inspection to small portions of an entire sewer system. Consequently, the threat posed by individual pipes that have not yet been inspected remains unquantified, creating a potentially dangerous and costly failure scenario for the municipality. As an example, the sudden failure of a 35-year old, 1.1 m diameter sewer pipe in Tucson, Arizona caused two large sink holes on a major five-lane roadway. The county was served with 11 environmental violations as an estimated 50 million gallons of raw sewage flowed into the nearby Santa Cruz River (Carlson and Urquhart 2006).

A systematic approach to predicting the condition of uninspected pipes is critical for the efficient use of limited financial resources. Sewer deterioration rates are highly dependent on a variety of factors (e.g. original design, material of construction, environmental conditions, extreme loading events, and asset age), which serves to make the characterization of time-dependent deterioration of individual pipes a challenging task. As a result, the majority of sewer deterioration models currently available focus on the provision of generalized estimates of condition at the system/network level. Models capable of predicting individual sewer pipe condition are still in their infancy as few studies have been devoted to model development and even fewer to model validation (Kley and Caradot 2013).

Hence, a framework is proposed for implementing an interpretable data mining system that is capable of learning from existing inspection datasets so that reliable conditions of prediction can be made for individual pipes in a sewer system that have not yet been inspected. Open-source software is utilized, making the data mining approach accessible to municipalities, regardless of pre-existing financial circumstance. The predictive capabilities of the model are illustrated using a case study representative of condition data typically available after a municipality inspects a portion of their sewer system. The modelling approach relies on a set of basic pipe-specific attributes when predicting pipe condition, ensuring it can be easily reproduced by other municipalities.

10.2 An Overview of Sewer Condition Modeling

Proactive management of aging sewer pipes can be supported by the use of pipe deterioration modeling strategies, the majority of which have their foundations in statistical theory (Ana and Bauwens 2010). Markov models developed for predicting the deterioration of stormwater pipes in Australia were not initially designed with the intention of predicting individual pipe condition (Micevski et al. 2002). A Markov process developed using inspections from more than 5,000 concrete sewer pipes in Germany successfully predicted the condition of individual pipes, but it was conceded that the approach involved heavy and cumbersome data manipulations (LeGat 2006). Markov models and ordinal regression models developed using 27 km of stormwater pipe condition in Australia were only useful at the system-level (predictive accuracy of the ordinal regression model for individual pipes was 42 %) (Tran et al. 2008). A Markov process proposed for evaluating the suitability of condition assessment technologies for water pipes in Hamilton, Ontario was not intended for predicting pipe condition (Atef et al. 2012).

The predictive capabilities of binary logistic regression to categorize the condition of PVC pipe segments in Phoenix, Arizona were not provided at the individual-pipe level (Koo and Ariaratnam 2006). A variety of regression models developed to predict the deterioration of sewers in Cincinnati, Ohio were either unsuitable (e.g. the available data violated assumptions necessary to perform ordinal regression) or achieved less than desirable levels of performance (e.g. 46 % of poor structural condition pipes were correctly predicted using a binary logistic regression model) (Salman 2010). Ordinal regression models provided insight into sewer pipe deterioration in Niagara Falls, Ontario but the predictive capabilities of the modeling approach were not provided at the individual pipe level (Younis and Knight 2010). Survival analysis models were used to predict structural condition at the system-level for cohorts of sewer pipes in Quebec City, Quebec (Duchesne et al. 2012).

Predictive models have also been developed using data mining techniques drawn from the intersection of statistics, artificial intelligence and machine learning. These techniques are capable of extracting information from large inspection datasets so that predictions of pipe condition can be obtained without the parametric assumptions that tend to restrict the utility of statistical approaches. Neural networks were superior to Markov models and ordinal regression when predicting the deterioration of stormwater pipes in Australia (Tran 2007). Neural networks were also used to investigate sewer pipe deterioration in Pierrefonds, Quebec (Khan et al. 2010). Support vector machines successfully predicted the structural condition of individual sewer pipes in Australia (Mashford et al. 2011).

The literature generally indicates no single modelling strategy works best for all predictive modeling tasks, a phenomenon that can be explained by the *no free lunch theorem of optimization* (Wolpert and Macready 1997). Although some approaches have provided high levels of predictive performance for some municipalities, predictions of condition made for another municipality using the same modeling strategy have been poor. As an example, Markov, survival, regression and neural network models were all found incapable of reliably predicting individual pipe condition in two Belgian municipalities (e.g. the neural networks often predicted pipe condition would improve over time, which would be impossible without some sort of rehabilitation) (Ana 2009).

Many municipalities will be unable to devote the development time necessary for a modelling strategy requiring extensive data manipulation, pre-processing and assumption making/validation. Municipalities need access to efficient alternatives capable of learning from existing inspection datasets so that location-specific pipe-level models can be obtained in a relatively short-period of time. Hence, an

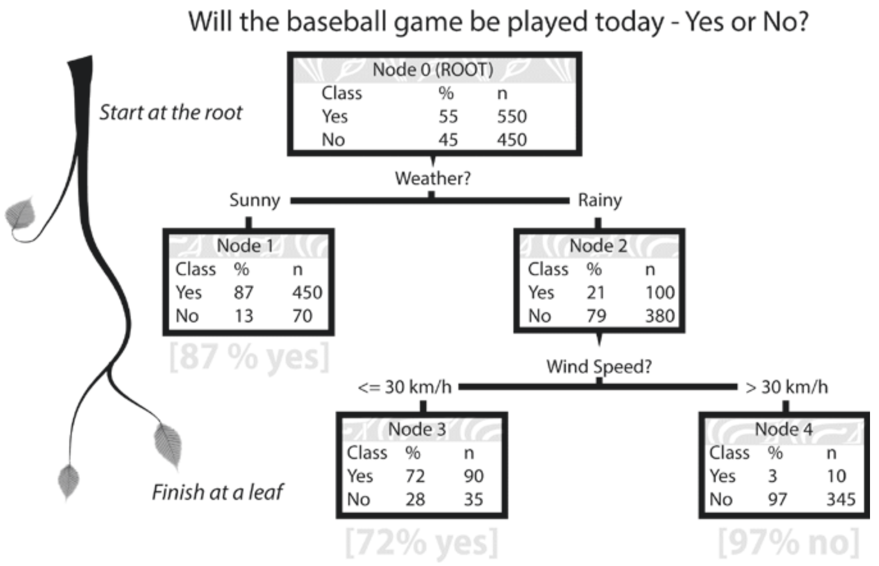

Fig. 10.2 A decision tree predictive model illustrates the knowledge gained from a hypothetical dataset in a tree-like format. In this example, the values of the input predictors (weather and wind speed) can be used to determine the likelihood of a game being played

efficiently implemented decision tree modeling strategy is described for predicting individual pipe condition. In general terms, decision tree algorithms learn from an existing dataset so that a flowchart-like tree structure can be obtained that illustrates relationships between input-predictors and a target class embedded within a dataset (Fig. 10.2). The resulting image of the tree is interpretable, even by those unfamiliar with the data mining process (unlike neural networks, which are black boxes).

The topmost node, called the root of the tree, contains all the instances/observations contained in a dataset used for training. Each internal node specifies a test on an input predictor and each branch in the tree represents an outcome of the test. An instance is classified by starting at the root of the tree and then, depending on the values of the attributes, tracing a path down through the branches of the tree. Eventually, a leaf node is reached at the bottom of the tree and a classification can be obtained using the distribution of instances observed in the leaf.

Decision trees are among the most popular data mining systems used within the fields of financial analysis, medicine and marketing. They have previously been used to model sewer collapse rates (Heywood et al. 2007) and to identify important attributes associated with high-density regions of defective pipes in a mid-sized city (Jung et al. 2012). These models effectively handle a wide variety of continuous data, categorical data, sparse data and skewed data and require very little in the way of data pre-processing and manipulation (unlike traditional statistical techniques). Feature selection (where the most useful input predictors are used to make predictions) is also implicitly conducted as part of the algorithm.

10.3 Data Mining Methodology

In data mining terms, a *decision tree classifier* needs to be trained using each instance/inspected pipe in the dataset so that a relationship can be made between input predictors and the target condition class. The input predictors are the pipe-specific attributes obtained from a facilities inventory maintained in an asset management system such as GIS or through field-investigation (e.g. each pipe in the inspection dataset has a unique material of construction, age, diameter and length). The initial targets are condition grades assigned to each inspected pipe (e.g. the Water Research Council Sewer Rehabilitation Manual (WRc SRM) internal condition grades (ICG) of 1, 2, 3, 4 or 5) (WRC 1996).

Inspection datasets tend to be imbalanced, with significantly more pipes in some condition classes than others. As a hypothetical example, inspecting 1,000 pipes may reveal 550 pipes in excellent condition (ICG 1), 200 in good condition (ICG 2), 150 in fair condition (ICG 3), 75 in poor condition (ICG 4) and only 25 that have failed (ICG 5). This imbalance is the natural result of collecting condition data over a limited time period (if inspections are performed over 5 years, any pipes in the sewer system prone to failure will have already failed and been replaced prior to inspection). Traditional data mining systems aim to minimize the total number of errors made during classification and tend to be most effective when there is a balanced distribution of observations across all classes in the dataset. Consequently, predictive models developed using imbalanced inspection datasets will be biased towards the majority classes (i.e. ICG 1 and 2) and will show poor classification rates for minority classes of interest (i.e. ICG 3, 4 and 5). The majority classes dominate the learning process and the resulting model will almost always predict a pipe belongs to the majority classes ICG 1 or 2.

Improving the classification accuracy of minority classes within an imbalanced multiclass dataset is a difficult task and remains an active area of research within the data mining community (Han et al. 2006). The majority of class-imbalance learning techniques currently available for implementation have been designed for two-class problems, necessitating transforming pipe condition into a two-class format. The transformation of pipe condition is typically the choice of the municipality and will reflect any local intentions to rehabilitate structurally damaged pipes. One option would be to assign ICG of 1–2 to a *good* condition class as these pipes have no defects or contain very few defects of concern. Pipes with an ICG of 3–5 can be assigned to a *poor* condition class as their structural defects pose a potential threat to the integrity of the sewer system and they would be potential candidates for rehabilitation. Although the distribution of instances across classes may still be imbalanced after this recoding of pipe condition (for the previously mentioned hypothetical 1,000 inspections, 75 % of the pipes would be *good* and 25 % would be *poor*), the binary format reduces the imbalance and facilities implementation of strategies designed to improve the ability to correctly identify *bad* pipes representing the positive, minority class of interest.

After transformation into a two-class format, the dataset is subdivided into training, evaluation and test sets using a 70–10–20 splitting ratio. The training set is used to train the model, the evaluation set is used during model tuning and the test set is used to provide an unbiased indication of the predictive capabilities of the model on previously unseen observations. Stratified random sampling should be used to ensure the class distribution in the three sets match (Kuhn and Johnson 2013).

A variety of techniques are currently available for constructing decision tree classifiers. One of the oldest and most widely used is the classification and regression tree (CART) methodology developed in the mid-1980s (Breiman et al. 1984). CART models in this research were trained and tuned using the *caret* (Kuhn 2013) and *rpart* (Therneau et al. 2014) packages developed for the open-source *R* software environment. The CART methodology constructs decision tree classifiers using a top-down divide-and-conquer approach—where instances of pipe condition in the training dataset are partitioned into small, *homogenous* groups that are *pure* (with a larger proportion of one class than another) (Kuhn and Johnson 2013).

Optimal splits for numeric input predictors (e.g. a pipe's length in meters) are determined by sorting all the available instances in the training set based on their predictor value. Any categorical input predictors considered for splitting (e.g. pipe material of construction) are first be decomposed into binary dummy variables prior to their presentation to the CART algorithm, forcing binary splits of the categories. The potential split points are then the midpoints between each unique predictor value and a contingency table is then generated for each potential split point (Table 10.1).

The purity of a potential split is determined using the *Gini* index, which can be calculated before and after a split for a two-class problem using the equations:

$$Gini(prior\ to\ split) = 2\left(\frac{n_{1+}}{n}\right)\left(\frac{n_{2+}}{n}\right) \tag{10.1}$$

$$Gini(after\ the\ split) = 2\left[\left(\frac{n_{11}}{n}\right)\left(\frac{n_{12}}{n_{+1}}\right) + \left(\frac{n_{21}}{n}\right)\left(\frac{n_{22}}{n_{+2}}\right)\right] \tag{10.2}$$

The CART algorithm evaluates all the potential split points and seeks out the one that minimizes the Gini purity criterion as it results in the least amount of randomness/impurity out of all the possible splits. This evaluation process then continues within each newly created partition of the tree and the tree grows larger as new splits are created. Trees may eventually grow so large that the splits being added only reflect anomalies in the training data due to noise. Unreliable branches can be removed from the fully-grown tree using a complexity parameter that is a function of the number of leaves in the tree and the error rate (the percentage of instances misclassified by the tree):

Table 10.1 Contingency table for each split point in the tree

	Class 1	Class 2	
>split	n_{11}	n_{12}	n_{+1}
≤split	n_{21}	n_{22}	n_{+2}
	n_{1+}	n_{2+}	n

$$Accuracy_{c_p} = Accuracy + c_p \times (\#\, of\ leaves) \tag{10.3}$$

The algorithm uses the complexity parameter when evaluating the impact on predictive performance when various sub-trees at a node are pruned away and the node itself is replaced by a terminal leaf (Kuhn and Johnson 2013). Given a particular value of the complexity parameter, the algorithm seeks out the tree having the best predictive performance on cross-validation partitions of the training set. A complexity parameter of zero results in a fully grown tree (potentially poor predictive capabilities) and values close to one might result in a tree with only one split (limited utility for knowledge extraction purposes).

The evaluation and testing datasets can be used to gauge the predictive capabilities of pruned decision tree model. The leaf nodes in the tree are used to generate a continuous-valued class membership probability between 0 and 1 established based on the distribution of condition classes at that leaf. By default, the tree uses a probability threshold of 50 % to assign a class label to any instances that reach that leaf. As an example, an individual pipe with attributes that lead it to a leaf in the tree with a distribution of 60 % *good* pipes and 40 % *bad* pipes, then the tree will predict that pipe belongs to the *good* condition class. These discrete class predictions can then be used to evaluate the performance of the model on a dataset with known class labels using the confusion matrix shown in Table 10.2.

When pipes in *poor* condition are considered the positive class of interest the following outcomes are shown in the confusion matrix:

- True positive = a pipe known to be in *poor* condition correctly predicted to be in the *poor* condition by the decision tree.
- False positive = a pipe known to be in *good* condition incorrectly predicted to be in *poor* condition.
- True negative = a pipe that is actually in *good* condition correctly predicted to be in *good* condition.
- False negative = a pipe that is actually in *poor* condition incorrectly predicted to be in *good* condition.

Ideally, there will be very few false positives and false negatives (i.e. highly accurate). Accuracy may not provide a reliable indicator of predictor performance for models trained using imbalanced datasets as it may provide a false impression of capabilities for the minority class of interest. Considering the hypothetical dataset of 750 pipes in *good* condition and 250 pipes in *poor* condition, assigning every pipe to the *good* condition class would achieve an accuracy of 75 %. Accuracy assumes the costs of false positive and false negative errors are the same. In reality false negatives have a much higher cost than false positives when predicting

Table 10.2 Confusion matrix for a binary classification task

		Predicted condition class	
		Poor (ICG 3–5)	Good (ICG 1–2)
Actual condition class	Poor (ICG 3–5)	True positive (TP)	False negative (FN)
	Good (ICG 1–2)	False positive (FP)	True negative (TN)

sewer condition. If an uninspected pipe was leaking raw sewage into the ground but the model predicted the pipe was actually in good condition (and therefore did not need to be inspected) there could be serious environmental and economic consequences. As a result, a series of alternative metrics should be used understand model utility when working with imbalanced datasets:

$$\mathit{True\ Positive\ Rate} = \mathit{sensitivity} = \frac{TP}{TP + FN} \tag{10.4}$$

$$\mathit{True\ negative\ rate} = \mathit{specificity} = \frac{TN}{FP + TN} \tag{10.5}$$

$$\mathit{False\ positive\ rate} = 1 - TNR = \frac{FP}{FP + TN} \tag{10.6}$$

$$\mathit{False\ negative\ rate} = 1 - TPR = \frac{FN}{TP + FN} \tag{10.7}$$

Class imbalance inevitably results in a trade-off between the true positive rate and the false positive rate. A useful tool for evaluating this trade-off is the receiver-operating characteristic (ROC) curve (Fig. 10.3). The ROC curve, first used during the Second World War to help radar operators correctly distinguish enemy targets

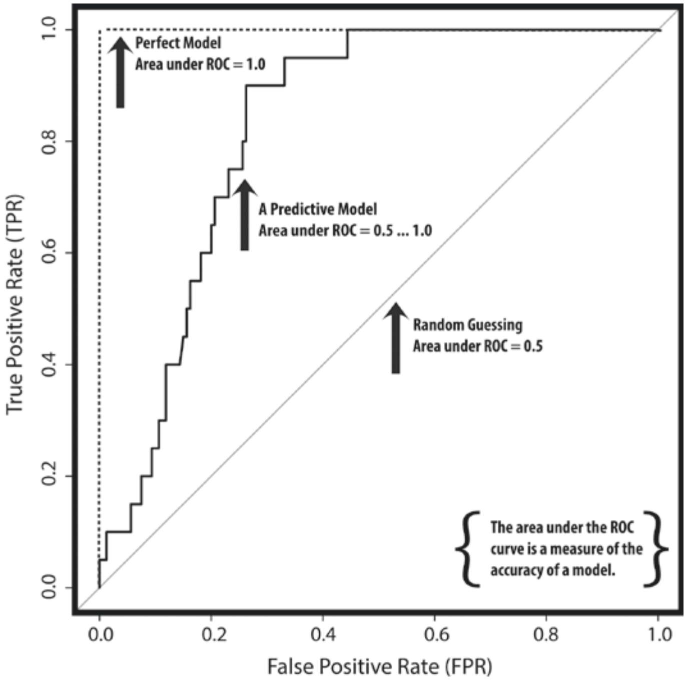

Fig. 10.3 The receiver operating characteristic (ROC) curve can be used to evaluate the trade-offs between true positives and false positives

from noise on their screens, is a plot of the true positive rate versus the false positive rate achieved when different probability thresholds are used to establish classifications for instances in a dataset. For each candidate threshold (e.g. 50 %) the true positive rate and false positive rate are plotted against each other.

The area under the ROC curve can be used to gauge model performance. Perfect models have an area under the ROC curve of 1 and random models have an area under the ROC curve close to 0.5 (Fawcett 2006). As a rough guide, an area under the ROC greater than 0.7 on a stratified test set would be considered acceptable (Hosmer and Lemeshow 2000).

A threshold-moving approach can be implemented to improve the identification capability for *poor* condition pipes representing the minority class of interest. This technique involves moving the classification threshold away from the baseline of 50 % so that minority classes are more frequently predicted. For example, a leaf in the tree may contain 35 % *poor* condition pips and 65 % *good* pipes and any instance that reaches that leaf will be classified as being *good*. Changing the threshold down from 50 to 30 % would then mean any instance that reaches that leaf will be classified as being in *poor* condition to reduce the likelihood of a costly false negative error. A new, optimal cutoff can be determined by finding the point on an ROC curve developed for the evaluation dataset that is closest to the top left corner as it is closest to the perfect model. This new threshold can then be used to reclassify pipes in the test dataset. Threshold moving has been empirically shown to outperform some of the other commonly used techniques to accommodate data imbalance (e.g. oversampling and undersampling) (Han et al. 2006). In addition to simplicity, the approach is advantageous as it does not alter the original tree structure of the trained model.

10.4 Case Study

The City of Guelph is located in southwestern Ontario, Canada. The 120,000 residents of the municipality are served by a 515 km long sanitary sewer system composed of more than 7,000 gravity sewer pipes.

A total of 221 km of Guelph's gravity sewer pipes were CCTV inspected from 2009 to 2011 by AECOM Canada Ltd. These inspections were carried out using the third edition of the Water Research Council Manual of Sewer Condition Classification (WRc MSCC) (WRc 1996). Defects observed inside each pipe were then assigned severity scores using the fourth edition of the Water Research Council Sewerage Rehabilitation Manual (WRc SRM). The peak score (highest defect value accumulated in any one meter length of a pipe) was used to assign an internal condition grade of 1–5 to each inspected pipe based on peak score threshold guidelines contained within the WRc SRM.

Comprehensive quality assurance/quality controlled was carried out by AECOM to ensure accuracy of the CCTV inspection records. The modeling dataset used for data mining purposes in this research consisted of 1,825 pipes

Table 10.3 The inspection dataset used for model development

	Internal condition grade (ICG)					Condition	
	1	2	3	4	5	Good (ICG 1–2)	Poor (ICG 3–5)
Asbestos cement	373	14	24	5	0	387	29
Concrete	364	79	73	36	7	443	116
PVC	110	9	1	2	1	119	4
Reinforced concrete	56	8	0	0	0	64	0
Vitrified clay	213	135	165	121	29	348	315
Total	1,116	245	263	164	37	1,361	464

(123 km) inspected by the primary sub-contractor (Table 10.3). There are significantly more pipes in ICG 1 than in classes 2–5 for the algorithm to learn from. A binary reclassification of condition (ICG 1–2 vs. 3–5) results in a 3:1 ratio of *good* to *poor* condition pipes.

Splitting the data using a 70–10–20 division created 1,278 instances (325 *poor* and 953 *good* condition), 183 instances for evaluation (47 *poor* and 136 *good*) and 364 instances for testing (92 *poor* and 272 *good*).

The following input predictors were considered during the process of training the decision tree: trunk sewer (categorical: yes or no), material of construction (categorical: asbestos cement, concrete, PVC, reinforced concrete, or vitrified clay), year of installation (numeric: 1902:2008), diameter (numeric: 200:900 mm), length (numeric: 3:200 m), slope (−5:16 m per 100 m), and burial depth (numeric: 0.8–8.8 m).

10.5 Results

A visual depiction of the decision tree classifier developed using the training dataset is shown in Fig. 10.4. Tree-pruning was carried out using an optimal complexity parameter of 0.0136 determined using *caret* (maximum ten-fold cross-validation area under the ROC curve = 0.76). The model achieved an area under the ROC curve of 0.77 for both the evaluation and test sets, which can be considered an acceptable result for a binary classification task. The test set confusion matrix developed for the default probability threshold of 50 % is given in Table 10.4. The table indicates the default probability threshold needed to be tuned to account for class imbalance. Although accuracy is fairly high (0.79), the false negative rate (0.49) indicates many *poor* condition pipes are misclassified.

The evaluation set ROC curve (Fig. 10.5) was used to identify a new, optimal threshold of 32.4 % (closest to the top left corner, therefore closest to a perfect model). The test set confusion matrix shown using this new threshold is shown in Table 10.5. Although this new threshold does slightly reduce the overall accuracy of the model from 0.79 to 0.76, the false negative rate drops significantly from

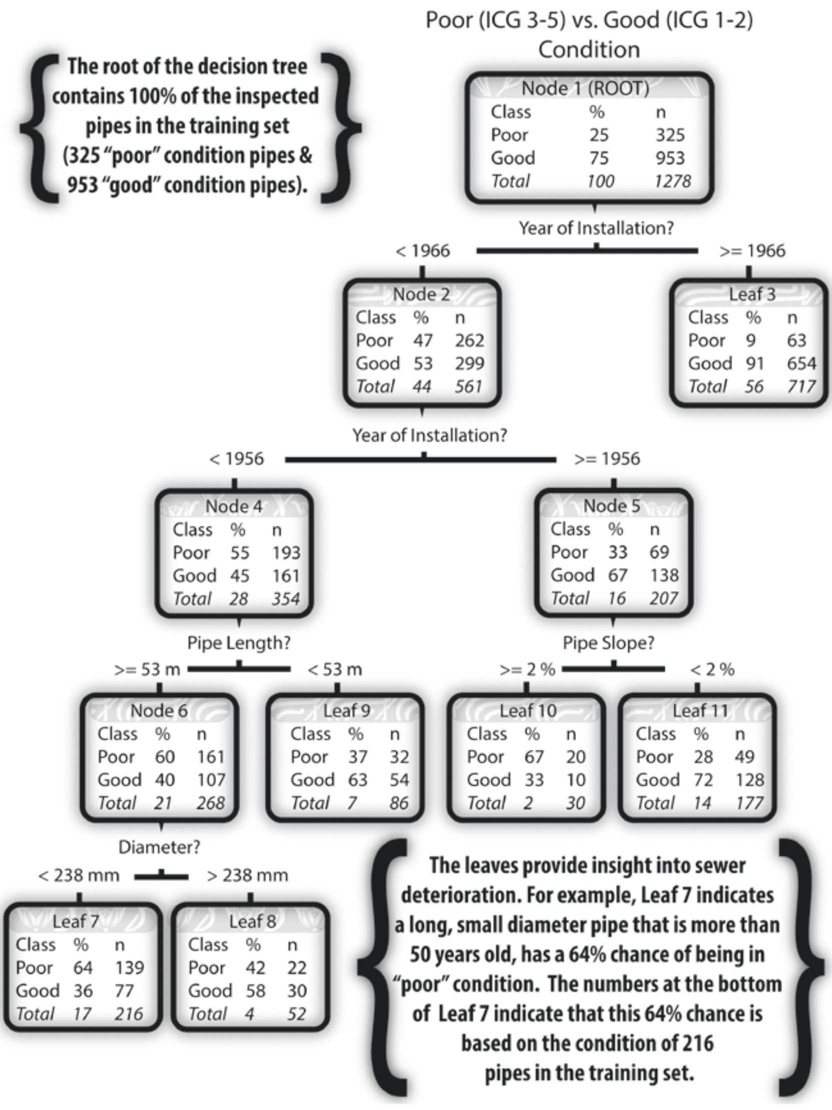

Fig. 10.4 The CART model for predicting sewer pipe condition

0.48 to 0.32 (with the consequences that the false positive rate slightly increased from 0.12 to 0.22).

Table 10.4 Test set confusion matrix for default classification threshold (50 %)

		Predicted condition	
		Poor (ICG 3–5)	Good (ICG 1–2)
Actual condition	Poor (ICG 3–5)	48	44
	Good (ICG 1–2)	33	239
Accuracy = (48 + 239)/(48 + 44 + 33 + 239) = (287)/(364) = 0.79			
True positive rate = (48)/(48 + 44) = (48)/(92) = 0.52 (correctly classified *poor* pipe)			
False positive rate = (33)/(33 + 239) = (33)/(272) = 0.12 (incorrectly classified *good* pipe)			
True negative rate = (239)/(33 + 239) = (239)/(272) = 0.88 (correctly classified *good* pipe)			
False negative rate = (44)/(48 + 44) = (44)/(92) = 0.48 (incorrectly classified *poor* pipe)			
Area under the ROC curve = 0.77			

Table 10.5 Test set confusion matrix for optimal classification threshold (32 %)

		Predicted condition	
		Poor (ICG 3–5)	Good (ICG 1–2)
Actual condition	Poor (ICG 3–5)	63	29
	Good (ICG 1–2)	59	213
Accuracy = (63 + 213)/(63 + 29 + 59 + 213) = 0.76			
True positive rate = (63)/(63 + 29) = (63) /(92) = 0.68 (correctly classified *poor* pipe)			
False positive rate = (59)/(59 + 213) = (59)/(272) = 0.22 (incorrectly classified *good* pipe)			
True negative rate = (213)/(59 + 213) = (213)/(272) = 0.78 (correctly classified *good* pipe)			
False negative rate = (29)/(63 + 29) = (29)/(92) = 0.32 (incorrectly classified *poor* pipe)			
Area under the ROC curve = 0.77			

Table 10.6 Test set confusion matrix for a classification threshold (20 %)

		Predicted condition	
		Poor (ICG 3–5)	Good (ICG 1–2)
Actual condition	Poor (ICG 3–5)	73	19
	Good (ICG 1–2)	97	175
Accuracy = (73 + 175) /(73 + 19 + 97 + 175) = 0.68			
True positive rate = (73)/(73 + 19) = (73)/(92) = 0.79 (correctly classified *poor* pipe)			
False positive rate = (97)/(97 + 175) = (97)/(272) = 0.36 (incorrectly classified *good* pipe)			
True negative rate = (175)/(97 + 175) = (213)/(272) = 0.74 (correctly classified *good* pipe)			
False negative rate = (19)/(73 + 19) = (19)/(92) = 0.21 (incorrectly classified *poor* pipe)			
Area under the ROC curve = 0.77			

A municipality could also choose to tune using a more severe classification threshold to further reduce the likelihood of a false negative. As an example, a threshold of 20 % would result in an overall accuracy of 0.68 but would achieve a false negative rate of 0.21 and a false positive rate of 0.36 (Table 10.6). The

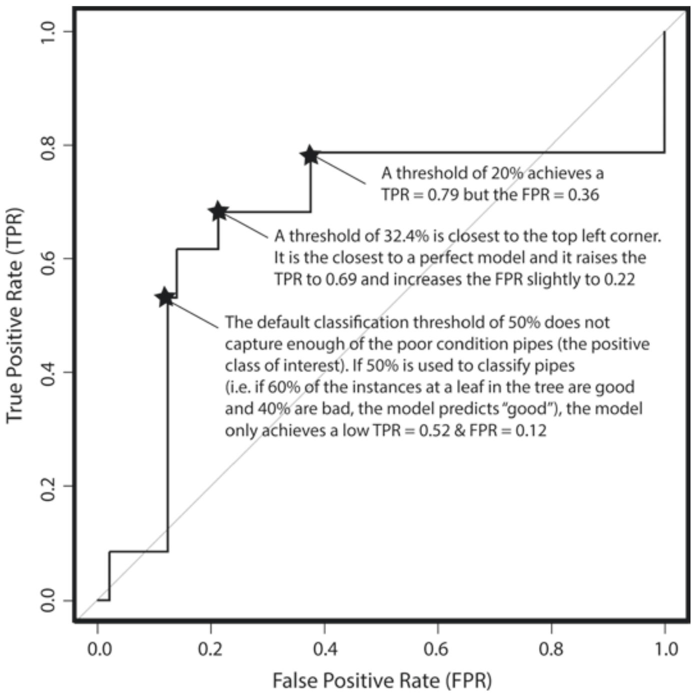

Fig. 10.5 The evaluation set receiver operating characteristic (ROC) curve indicates an alternative threshold could reduce the false negative rate of the tree

desirability of this alternative threshold is dependent on the municipality's desire to reduce the risk of missing poor condition pipes.

10.6 Discussion

The branches and leaves of the tree provide insight into local pipe deterioration processes occurring in the municipality. The first major split of the tree partitions pipes in the training set according to their year of installation. In Guelph, 91 % of the pipes installed after 1966 (i.e. less than 50 years old) are in good condition (leaf 3). Although there are some newer pipes in *poor* condition, no further splits after leaf 3 would increase purity of the dataset. Alternatively, 47 % of all pipes in the training dataset installed prior to 1966 are in *poor* condition. Nodes 4 and 5 of the tree indicate installation year can further subdivide the dataset as 33 % of pipes installed between 1956 and 1966 are in *poor* condition (node 5) compared to the 55 % of the pipes installed prior to 1956 that are in *poor* condition (node 4).

Pipes constructed between 1956 and 1966 having a slope greater than 2 m/100 m have a 67 % chance of being in *poor* condition (leaf 10) compared to a 28 % chance of being in *poor* condition when slope is less than 2 m/100 m (leaf 11). A possible explanation for this phenomenon is that pipe sections with steep slopes tend to have higher deterioration rates as flows are generally faster in these steep sections, causing erosion and surface wear inside the pipe.

The influence of pipe length on the condition of pipes installed prior to 1956 is shown in node 8 and leaf 9. It has been suggested in the literature that longer sections of pipe have more joints and tend to deteriorate at faster rates than shorter ones (Ana and Bauwens 2010). Node 6 indicates pipes with a length greater than 53 m have a 60 % likelihood of being in poor condition, which is significantly higher than the 37 % likelihood for pipes with a length less than 53 m (leaf 9).

Pipe diameter is also found to be related to pipe structural condition. Leaf 7 indicates there is a 64 % chance of being in poor condition if the diameter of older, longer pipes is less than 238 mm. Pipes with a diameter greater than 238 mm have only a 42 % chance of being in *poor* condition (leaf 8). One possible explanation for the reduced likelihood of larger diameter pipes being in *poor* condition could be the tendency of larger diameter pipes to be installed by experienced personnel, reducing the likelihood of defects related to installation error (Davies et al. 2001).

10.6.1 Planning Future Inspections

The City of Guelph has a significant portion of their sanitary sewer system that has not yet been inspected (although the majority of these pipes are newer PVC pipes installed within the past 50 years, approximately 800 pipes were installed prior to 1966). The unique attributes of the uninspected pipes can be presented to the decision tree and the predicted probability of being in *poor* condition can be used to identify pipes that should be scheduled for the next round of inspections. Using the optimal probability threshold of 32 %, a total of 624 pipes are predicted to be in *poor* condition.

A municipality may not have the time or the budget required to immediately inspect every pipe identified by the decision tree as being in poor condition. An alternative to the immediate inspection of all *poor* predicted pipes would be the selection of a smaller subset of pipes that are of concern due to their proximity to other deteriorated municipal infrastructure. A number of recent studies indicate defective stormwater pipes are a conduit for raw sewage when leaking sanitary pipes are located in close proximity (Doshi 2012; Sercu et al. 2011). Raw sewage passing untreated from broken sewer pipes into broken stormwater pipes has the potential to cause widespread contamination of municipal waterways and beaches.

The City of Guelph inspected one-third of their stormwater system from 2008 to 2011. Of the 2,460 inspected stormwater pipes, 903 were found to be in poor structural condition with an ICG of 3–5. Of the 624 sanitary sewer pipes predicted by the decision tree to be in *poor* condition, 25 have a probability of being in *poor* condition of at least 50 % and are located within one meter of an ICG 3–5 stormwater pipe (Fig. 10.6). Securing the budgetary allocation for the immediate inspection of 25 pipes should prove to be an easier task than inspecting 624 pipes.

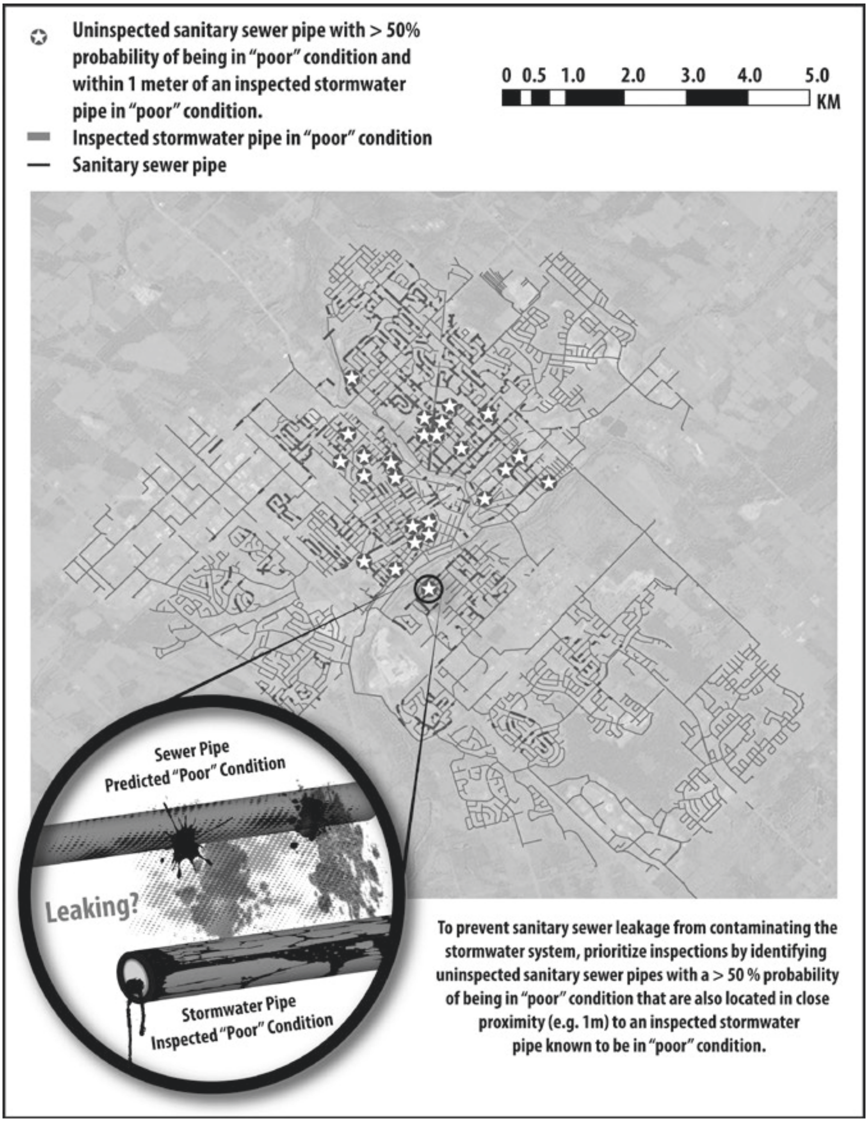

Fig. 10.6 Sanitary sewer pipes predicted to be in poor condition by the decision tree model that are also located in close proximity to a defective stormwater pipe are candidates for immediate inspection

10.6.2 Future Directions of Research

The CART predictive model achieved an acceptable area under the ROC curve of 0.76, but improvements in predictive performance should be pursued in future research. Advanced algorithms such as "random forests" may increase the capability of a predictive model to accurately identify pipes in poor structural condition. Random forests use the combined predictions of hundreds of trained CART models to make predictions and have been proven to outperform single decision trees on a variety of data mining tasks (Kuhn and Johnson 2013).

An alternative encoding can be used to represent pipe condition for municipalities seeking alternative predictions of condition. It may be more beneficial to encode pipes as being in either ICG 123 versus 45 as pipes with an ICG ≥ 4 have serious defects and can be expected to collapse or will collapse within a short time frame. One consequence of this alternative encoding is that the class imbalance problem will be more severe.

While the suggestion of targeting pipes for inspection based on their proximity to poor condition stormwater pipes is novel, a more elaborate risk of failure scenarios would allow municipalities to further assess the suitability of candidate pipes for inspection. As an example, there would be utility in assessing the consequences of failure associated when pipes are located within clusters of poor condition pipes identified through hotspot analysis of network infrastructure.

10.7 Conclusion

Sewer pipe deterioration is a major concern as broken pipes pose a threat to the environment and to the financial well-being of municipalities. There have been very few validated predictive models made available to municipalities across North America that are capable of identifying the location of individual, poor condition pipes in a sewer system. The popular classification and regression tree (CART) system was used to construct a predictive model capable of identifying individual pipes in a sewer system that are most likely to be in poor structural condition. Imbalance common within inspection dataset was accommodated by using a technique of adjusting the baseline probability threshold used by the CART model when making binary classifications of pipe condition.

The City of Guelph, Ontario inspected a portion of their sanitary sewer system from 2008 to 2011. The CART algorithm extracted information from Guelph's existing record of CCTV inspection. The model provides a visual guide to the influence of pipe-specific attributes on structural condition. The majority of sanitary sewer pipes built after 1966 are in good structural condition as they have not yet reached the end of their 50-year design life. The tendency for steeper slopes to be in poor structural condition is depicted for pipes installed between 1956 and 1966. Pipes installed prior to 1956 with a length greater than 53 m have a 55 % chance of being in poor condition, compared to a 37 % chance for shorter pipes. Older pipes with lengths greater than 53 m have a 64 % chance of being in poor condition in poor condition if they have diameters less than 238 mm, compared to a 42 % chance for larger diameter pipes.

A significant portion of the Guelph sanitary system has not yet been inspected. The model predicts 624 of these pipes are in poor condition. A subset of these pipes can be scheduled for immediate inspection using their proximity to other failed infrastructure. In Guelph, 25 of the 624 pipes are within one meter of an inspected stormwater pipe that was already found to be in a failed condition state. It is possible that sewage is leaking from these 46 sanitary sewer pipes and then entering into the stormwater system, where it inevitably contaminates outfall areas (i.e. rivers, lakes and beaches).

The data mining methodology was designed with an intention for efficient implementation. Localized predictive models can be developed for any municipality with inspection data in a similar format to Guelph's. These predictive models can enhance a municipality's understanding of life-cycle degradation of sanitary sewer pipes and can serve as a consensus-building tool for the allocation of municipal funds towards future pipe inspection.

Acknowledgments The authors would like to thank the City of Guelph for the provision of the sanitary sewer inspection records and assistance throughout the research process. Thank you to Adam Bonnycastle and the Department of Geography at the University of Guelph for assistance with GIS analysis. The University of Guelph, the Natural Sciences and Engineering Council of Canada and the Canada Research Chairs program funded this research.

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Chapter 11
Bargaining Under Uncertainty: A Monte-Carlo Fallback Bargaining Method for Predicting the Likely Outcomes of Environmental Conflicts

Kaveh Madani, Laleh Shalikarian, Ahmed Hamed, Tyler Pierce, Kondwani Msowoya and Christopher Rowney

Abstract This chapter develops a method for analyzing bargaining problems in which the bargainers are uncertain about the performance of alternative bargaining outcomes. Monte-Carlo selection is combined with fallback bargaining (FB) in order to map the stochastic bargaining problem into many deterministic bargaining problems which can be analyzed using various fallback bargaining methods, namely unanimity FB, q-approval FB, and FB with impasse. The proposed method is applied to the California's Sacramento-San Joaquin Delta benchmark problem. In this problem the stakeholders need to reach an agreement over a water export strategy to address the current crisis in the Delta. This problem is modeled here as a bargaining game in which the environmentalists and water exporters develop a resolution through a bargaining process while the performances of different water export alternatives are uncertain. The analysis results are consistent with the findings of other studies using different decision analysis methods to analyze this multi-decision maker problem. Construction of a peripheral canal or a dual conveyance is expected if the parties change their cooperation attitudes, trying to benefit from a low level of cooperation in solving the Delta problems.

Keywords Fallback bargaining · Conflict resolution · Monte-Carlo multi-criteria decision analysis · Uncertainty · Stochastic decision making · Sacramento-San Joaquin delta · California

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_11

11.1 Introduction

Decision making for optimal management of water and environment is challenging due to presence of multiple stakeholders with different interests, championing conflicting objectives and solution alternatives (Mirchi et al. 2010). Selection of the optimal management strategies becomes even more challenging with the uncertainties due to imperfect foresight and the changing environment. Bargaining is used as a group decision-making method to develop consensus among environmental stakeholders and resolve environmental conflicts (Bruce and Madani 2014). In a successful bargaining process at least one party falls back in order for a settlement to be reached.

Fallback bargaining (FB) (Brams and Kilgour 2001) is a method for predicting the likely outcome of bargaining procedures. FB simulates the behavior of bargaining parties who fallback in lockstep from their most preferred solution or alternative to a less desired solution until an agreement is reached. For instance, let's assume two parties who rank a set of alternatives: A, B, C, D, and E, differently. The two parties are tasked with choosing a single alternative out of the choices given. Party 1's order of preference is D, C, B, A and E ($P_1 = D > C > B > A > E$) and would choose alternative D if it were the single decision maker. However, party 2's preference order is B, A, E, D, and C ($P_2 = B > A > E > D > C$) and would choose alternative B on its own. In this case, the two parties do not agree on their most preferred alternative and must, therefore, compromise to reach an implementable solution. In a bargaining process, these parties need to fallback in lockstep to their second choices (C and A) because they cannot agree on their first choices (D and B). As there is still no common alternative, the parties fallback once more to their third choices (B and E). As party 2 has already shown a preference for alternative B and party 1 now reveals alternative B as an acceptable solution out of those remaining, alternative B is the winning choice. As the winning choice's lowest position, among the bargainers involved, is on the third tier, this is considered a depth three agreement. This common agreement, which becomes the winning outcome of the procedure, leads to Pareto-optimal outcome that maximizes the bargainers' minimum satisfaction (Brams and Kilgour 2001).

FB methods can be used as a practical and useful method to simulate the decision making process involving multiple decision makers (Sheikhmohammady and Madani 2008). As game-theoretic methods, these methods help developing a reliable understanding and interpretation of stakeholders' behaviors in multi-decision-maker hydro-environmental management problems which usually involve conflicts (Madani 2010, 2013). Given that water and environmental problems often involve uncertainty it is important to develop a method which takes into account the effects of uncertainty on the decision making process. Therefore, the main purpose of this chapter is to develop a method for dealing with uncertainty in performances of different alternatives in group decision making using bargaining. For this purpose FB is combined with Monte-Carlo selection. The resulting method determines the ranking distribution of each alternative, reflecting their potential for being selected as the best alternative and their degree of ranking robustness. The proposed method is applied to the Sacramento-San Joaquin Delta conflict as a benchmark stochastic multi-participant decision making problem to predict the likely outcome of this group decision making process in which the parties are not necessarily willing to implement the social planner (system's optimal) solution and have shown interest in adopting a non-cooperative bargaining approach for decision making, resulting in a stable outcome (Read et al. 2014). It must be noted that although parties do not fully cooperate to implement the social planner's solution (Madani et al. 2014a) or the socially optimal solution selected through social choice (voting) methods (Madani et al. 2014b), involvement in a bargaining approach implies existence of a low level of cooperation. This level of cooperation is required for parties to get involved in a bargaining process and can result in outcomes, which are Pareto-superior to what can be obtained through a fully non-cooperative conflict resolution process (Madani and Lund 2011; Madani and Hipel 2011).

Located at the confluence of the Sacramento and San Joaquin Rivers, the California's Sacramento-San Joaquin Delta is a major source of water supply for the state of California. The Delta supplies water to 25 million urban residents and approximately two million acres of farmland. It is home to a variety of native endangered and threatened species and has a unique ecosystem with more than 750 species of flora and fauna (Lund et al. 2007, 2010; Tanaka et al. 2011). Despite the Delta having a rich agricultural land that contributed over \$500 million crop value in 1990s, it is exceptional in that it is a source of fresh water for the state of California. The Delta intercepts 40 % of the runoff from California's total land area and about 50 % of the state's total stream flow. The current state of the Delta is notably different from its original 500,000 acres of tidal marshland. Land subsidence of the islands, diverse agricultural activities, recreation and growing urbanization are some of the current characteristics associated with the Delta. These traits, in addition to sea level rise, earthquakes, climate change, floods, invasive species and a perpetual decline in native species have led to a general conclusion that the current use of Sacramento-San Joaquin Delta's land and water is unsustainable. Reliability and sustainability of the Delta is further threatened by water export from the Delta (Lund et al. 2007, 2010; Suddeth et al. 2010).

Considering the multiplicity of stakeholders' interests in the Delta, espousing new strategies to secure the Delta against current threats and to prevent tragic outcomes for the Delta's future would not be convenient (Madani and Lund 2012). To solve the Delta problem, Lund et al. (2010) suggested four options for central water export. These are: (1) continuing the Delta export as usual (CDE), (2) constructing a peripheral canal to convey water around the Delta (PC), (3) constructing a dual conveyance system for water transfers (DC) and (4) stopping the water export (SE).

To evaluate the aforementioned options, two important criteria representative of a variety of the main stakeholder interests in the Delta were considered, namely; economic performance and environmental sustainability (Lund et al. 2010). Performance of each of the four suggested options was evaluated according to these two criteria through survey from experts (Lund et al. 2008), as shown in Table 11.1. Cost (economic performance) of each alternative is a major concern for the Delta

Table 11.1 Performance range of Delta water export strategies under economic and environmental sustainability criteria (Lund et al. 2008, 2010)

Water export alternative	Cost (billion \$/year)	Fish survival
CDE	0.55–1.86	5–30
PC	0.25–0.85	10–40
DC	0.25–1.25	10–40
SE	1.25–2.5	30–60

water exporters. Construction costs, maintenance costs and costs of failure of the alternative constitute the overall cost of an alternative. It is assumed that environmentalists are supposed to be mainly concerned about the fish survival. Therefore, fish (delta smelt) survival is considered to be a rational performance indicator of environmental sustainability of each of the four water export options (Lund et al. 2008).

In this study, we employ three FB methods, namely (1) Unanimity Fallback Bargaining, (2) q-Approval Fallback Bargaining, and (3) Fallback Bargaining with Impasse, to determine a possible settlement to California's Sacramento-San Joaquin Delta conflict over selection of a water export strategy.

In the next section of this chapter we formulate the Delta FB problem as a deterministic bargaining problem involving two bargainers. Then we introduce and apply FB methods in order to find the possible outcome(s) of the deterministic bargaining procedure. We also combine Monte-Carlo selection with FB methods in order to examine whether or not the resolution (outcome) differs when uncertainties are involved. This process helps to ensure reliability of the predicted outcome in face of the given uncertainties in the performance values. The last section of the chapter concludes.

11.2 Deterministic Fallback Bargaining

As indicated by the values in Table 11.1, the performance of each alternative is subject to uncertainties. To illustrate the FB methods, the Delta problem is first solved in a deterministic form. Performance averages are used so as to imply how, on average, decision makers might rank the alternatives. The matrix below presents the performance averages of the alternatives in cardinal form. Each column represents the performance values considered by one of the two main decision makers in the Delta problem. The first column (cost indicated by C) represents the utility of the water exporters from each alternative and the second column (fish survival indicated by FS) represents the utility of the environmentalists.

$$Performance_{cardinal} = \begin{matrix} \\ CDE \\ PC \\ DC \\ SE \end{matrix} \begin{matrix} \text{C} \quad \text{FS} \\ \begin{bmatrix} 1.205 & 17.5 \\ 0.550 & 5.0 \\ 0.750 & 25.0 \\ 1.875 & 45.0 \end{bmatrix} \end{matrix}$$

Given that FB methods consider ordinal (ranking) information for determining the solution, the above cardinal matrix can be simplified to an ordinal matrix presented below. The ordinal matrix illustrates stakeholders' preferences over the possible Delta export alternatives. In the ordinal preference matrix, a higher rank (1 = highest rank) of an alternative by a decision maker reflects its higher desirability for that decision maker. Here, the water exporters prefer a lower cost and the environmentalists prefer a higher fish survival rate.

$$Performance_{Ordinal} = \begin{array}{c} \\ CDE \\ PC \\ DC \\ SE \end{array} \begin{array}{c} \begin{array}{cc} \mathrm{C} & \mathrm{FS} \end{array} \\ \begin{bmatrix} 3 & 3 \\ 1 & 2 \\ 2 & 2 \\ 4 & 1 \end{bmatrix} \end{array}$$

The Delta problem is considered as a bargaining problem in which stakeholders bargain based on their preferences over the water export alternatives. For such a problem FB methods can be applied to predict plausible outcome(s) (Sheikhmohammady and Madani 2008). However, to develop a compromise, they have to fall back in lockstep to a less preferred alternative until alternative with sufficient support is reached (Brams and Kilgour 2001). Based on the FB method applied, the definition of sufficient support varies. In the following sections, three different FB methods are defined and applied to the deterministic Delta decision making problem.

11.2.1 Unanimity Fallback Bargaining

The depth of agreement is the level of support at which a compromise set is acceptable (Sheikhmohammady et al. 2010). In Unanimity FB (UFB) (Brams and Kilgour 2001), the stakeholders indicate their support for the alternatives. The alternative(s) which receives all stakeholders' support with the highest possible quality is the selected outcome. If a decision rule other than unanimity is used, the selected outcome may differ. The outcome of UFB is Pareto-optimal, but not necessarily unique. The alternative(s) selected under UFB is at least average in each bargainer's ranking order (Brams and Kilgour 2001). The compromise set under the UFB method exactly includes the alternatives which maximizes the minimum satisfaction over all bargainers (Brams and Kilgour 2001; Sheikhmohammady and Madani 2008). The number of supporters for the water export alternatives in the Delta problem is presented in Table 11.2. In this problem SE, stopping the water export, is the most preferred alternative by the environmentalists. In the second level of preference, they prefer PC, constructing a peripheral canal to convey water around the Delta and DC, constructing a dual conveyance system for water transfers, equally. On the other hand, the water exporters place PC at their first preference level and DC at their second preference level. Therefore, under the UFB method, alternatives PC and DC are suggested as the most possible outcomes of the Delta bargaining problem because both options reach universal support at the second level.

Table 11.2 Number of supports for each alternative at different preference levels

Alternative	1st	2nd	3rd	4th
CDE	0	0	2	2
PC	1	2	2	2
DC	0	2	2	2
SE	1	1	1	2

11.2.2 q-Approval Fallback Bargaining

q-Approval FB selects the alternative(s) receiving the support of at least q bargainers ($1 \leq q \leq n$) as the most possible bargaining outcome, where n is the number of bargainers required for acceptance at the highest possible level (Brams and Kilgour 2001). If an alternative is accepted by at least q bargainers it is added to the compromise set. q-Approval may be appropriate for a bargaining situation in which there are multiple winners and one wishes to achieve proportional representation. Under q-Approval FB, ties are broken according to the quality of support and this method seeks to maximize the minimum dissatisfaction of q most satisfied bargainers. Therefore, under this method, when more than one alterative receive the minimum required level of support at a given preference level, the alternative with the strongest quality of support (highest number of supporters) is the winner (Brams and Kilgour 2001).

In the Delta problem $n = 2$, so q can be either 1 or 2. In the case when $q = 1$, the alternative(s) which receive at least one support at the highest quality should be selected based on 1-Approval FB. For the environmentalists SE is the most preferred alternative. For the water exporters, however, PC is the most preferred alternative as indicated in Table 11.2. Therefore, SE and PC are the most likely outcomes of the Delta problem under the 1-Approval FB method. In this case, since both alternatives have one supporter, there is no need for breaking ties and both alternatives should be selected as winners. When $q = 2$ for q-Approval, the problem becomes the same as UFB and PC and DC are the most likely bargaining outcomes.

11.2.3 Fallback Bargaining with Impasse

Additional data might be obtainable whereby bargainers could make use of an "impasse" in their rankings, indicating an outcome below which they would prefer no agreement (Brams and Kilgour 2001). The impasse itself could then become the fallback outcome, foreclosing any agreement and choosing to walk away (Behmanesh et al. 2013). Each bargainer's impasse level is indicated by "*I*" in his preference ranking. Beside the other alternatives to agree upon, a new alternative to the bargainers is presented with the permission to impasse (IMP). In a situation in which the bargainer prefers "no agreement" over an alternative, IMP may be chosen, and it is considered as an arbitrary point below which a bargainer would not descend (Brams and Kilgour 2001; Sheikhmohammady and Madani 2008). Therefore, when a bargainer realizes that descending from some alternative is not beneficial, IMP or no agreement may be selected. IMP can be ranked at any level after the most preferred alternative.

After letting the parties add IMP to their preference matrices, the problem can be solved using UFB or q-Approval FB. Therefore, the FB with impasse method produces a set of Pareto-optimal alternatives, which can include IMP. This set maximizes the minimum satisfaction of the bargainers. However, with addition of IMP, the selected Pareto-optimal excludes certain alternatives that, without IMP, might have been considered satisfactory (Brams and Kilgour 2001). In the Delta Problem, reliable information about how the stakeholders might rank IMP in their preference matrix is missing. Therefore, for illustration purposes, it is assumed that IMP could be placed at any level lower than the first preference level by the decision makers. For cost, IMP can be positioned at level two through five, establishing four unique orders. Whereas for fish survival, IMP can only be placed at level 2, 3 and 4 of the alternatives given that PC and DC have the same ordinal rank. Therefore, 12 different combinations (4 orders for cost and 3 orders for fish survival) can be generated to analyze the Delta problem using FB with impasse. Since IMP can rank from 2 to 4 under the fish survival criterion and 2–5 under the cost criterion in this problem, 12 different ordinal preference matrices can be generated to represent the Delta decision making problem if impasse is allowed. This is based on different possible combinations of the preference orders of the two bargainers over the 5 possible alternatives under consideration (CDE, PC, DC, SE, and IMP). Since the most likely position of the IMP option in the bargainers' preference order is unknown, it is assumed that all 12 ordinal preference matrices are equally likely. FB methods can be used to determine the most likely outcome(s) for each of the 12 bargaining games. The probability of being selected as the resolution of the bargaining game is then calculated for each alternative through dividing the number of times it is selected as the bargaining solution by 12. Given that the solution based on 1-Approval FB is not practical in a bargaining problem with two members, it is reasonable to use UFB (same as 2-approval FB in this case) to determine the likely outcome of the bargaining problem with impasse.

Table 11.3 shows the probability of being selected as the bargaining resolution for each alternative for the bargaining game with impasse, using the UFB method. Given that ties are possible, the selection probabilities exceed 100 %. The most likely outcomes are PC and DC which have the highest probability of being an outcome, 67 and 50 %, respectively. It is noteworthy that IMP is also a likely outcome of the

Table 11.3 Outcomes of the Delta bargaining problem involving IMP

Alternative	Probability of being an outcome under UFB (%)
CDE	0
PC	67
DC	50
SE	8
IMP	25

Table 11.4 FB outcomes in the deterministic mode

FB method	Likely outcomes
UFB	PC, DC
1-Approvall FB	PC, SE
FB with impasse	PC, DC

bargaining process one-fourth of the time. This result is consistent with the findings of Madani and Lund (2011, 2012), suggesting that "no resolution" is a weak equilibrium (likely outcome) of the Delta conflict in absence of willingness to cooperate.

The likely outcomes of the Delta's deterministic bargaining game under different FB methods are summarized in Table 11.4. PC is the most likely bargaining outcome, followed by DC. The 1-Approval FB does not simulate the bargaining process realistically and therefore may not be a reliable method in predicting the outcome of the Delta bargaining game. Reaching an agreement between two equally powerful bargainers is possible only when both parties support the final resolution. Therefore, SE is not likely to be the final outcome of the Delta bargaining problem.

11.3 Stochastic Fallback Bargaining

Although taking performance averages may simplify the analysis of stochastic data in group decision making problems, the final results may not be reliable as it overlooks the robustness of the selected outcomes (Madani et al. 2014b). To deal with the uncertainty in performance ranges of the alternatives in the Delta problem Madani and Lund (2011) suggested a Monte-Carlo game theory approach. Based on this procedure, random preference matrices are generated based on a Monte-Carlo selection method and then solved according to non-cooperative game theoretical concepts. Similarly, Monte-Carlo multi-criteria decision making (MCDM) and Monte-Carlo social choice making methods were respectively developed by Mokhtari et al. (2012) and Madani et al. (2014b) to evaluate the sensitivity of the Delta problem's solutions to different levels of cooperation. Based on the same concept, a Monte-Carlo FB approach is used here to account for the uncertainty in the decision making problem's input variables and to evaluate the robustness of the likely outcomes.

In each round of a Monte-Carlo selection the Delta problem is solved using different FB methods. As done by Madani and Lund (2011), for illustration purposes, uniform probability distributions are used in the Monte-Carlo selection process to generate random performance numbers out of the performance ranges in each round of the Monte-Carlo selection. The resulting deterministic problem is then used using different FB methods. The probability of being selected as the outcome of the bargaining process is updated for each alternative in each round. Table 11.5 shows the likelihood of each alternative being selected as the bargaining solution according to UFM, 1-Approval FB, and FB with impasse. Given that 1-Approval FB is not practical in a 2-bargainer problem, it can be concluded from the results that PC and DC are the most likely outcomes if parties decide to select the water export alternative through a bargaining process. When impasse is allowed, the bargaining process the parties might not settle over any of the four suggested alternatives.

In addition to calculating the winning probability for each alternative, i.e. probability of being selected as the best alternative (Table 11.5), ranking distribution of each alternative can be determined in order to evaluate the robustness of winning probabilities (Madani et al. 2014b). To determine the ranking distribution of alternatives, the alternatives must be fully ranked in each round of Monte-Carlo selection. Therefore, once the bargaining solution is determined in a given round under a given FB method, rank 1 is assigned to this alternative. This alternative is then removed and the FB analysis is continued with the remaining alternatives to determine the next best alternative (rank 2). This process is continued until all alternatives are ranked in a given round of Monte-Carlo selection. Through repetition of this process in each round of Monte-Carlo selection, the overall probability of ranking at each level can be determined for each alternative. The resulting ranking distribution

Table 11.5 Probability of being selected as the bargaining outcome under different bargaining methods

	CDE (%)	PC (%)	DC (%)	SE (%)	IMP (%)
UFB	15	52	50	1	–
1-Approval FB	3	69	33	90	–
FB with impasse	1	47	42	1	16

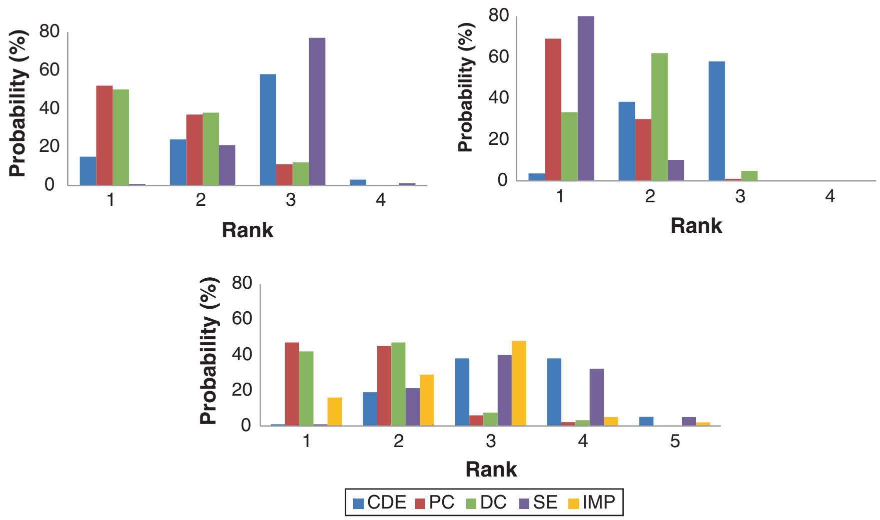

Fig. 11.1 Ranking distributions of water export alternatives based on the UFB (*top-left*), 1-Approval FB (*top-right*) and FB with impasse (*bottom*) methods

reflects the degree of ranking robustness for each alternative (Madani et al. 2014b). Ideally, one would prefer a narrower (more robust) probability distribution.

Figure 11.1 shows the ranking distributions of different water export alternatives in the Delta problem under the UFB (top left), 1-Approval FB (top right) and FB with impasse (bottom). As an example of robust ranking one can refer to SE under 1-Approval FB. This alternative has a narrow distribution, concentrated in the first and second levels. On the other hand, a good example of non-robust ranking is CDE under the UFB or FB with impasse methods. The ranking distribution of this alternative is wide and covers all ranking levels, so, it can be considered as a risky option. Given that 1-Approval FB is not realistic in the Delta case, based on Fig. 11.1, PC and DC are the most likely and robust outcomes if the water export alternative were to be selected through a bargaining process.

Table 11.6 compares the results obtained in this study with previous studies that used different decision analysis methods to study the Delta's benchmark problem. This table reflects the sensitivity of the results to the cooperation strategy of the

Table 11.6 Different approaches to solve the Delta problem

Cooperation strategy	Method (rule)	Ranking
Fully non-cooperative (Madani and Lund 2011)	Game theory (weak equilibrium)	CDE > PC > DC > SE
Partially cooperative (low level cooperation)	Fallback bargaining (unanimity)	PC > DC > CDE > SE
	Fallback bargaining (1-Approval)	SE > PC > DC > CDE
	Fallback bargaining (with impasse)	PC > DC > IMP > CDE > SE
Cooperation through coalition formation (Madani and Lund 2011)	Game theory (strong equilibrium)	PC > DC > CDE > SE
Partially cooperative (high level of cooperation) (Madani et al. 2014b)	Social choice (Borda score)	PC > DC > SE = CDE
	Social choice (condorcet choice)	PC > DC > CDE > SE
	Social choice (plurality)	SE > PC > DC > CDE
	Social choice (median voting)	PC > DC > CDE > SE
	Social choice (majoritarian compromise)	PC > DC > CDE > SE
	Social choice (condorcet practical)	PC > DC > CDE > SE
Fully cooperative (Mokhtari et al. 2012)	MCDM (lexicographic)	PC > DC > SE > CDE
	MCDM (SAW)	PC > DC > SE > CDE
	MCDM (TOPSIS)	PC > DC > SE > CDE
	MCDM (MAXIMIN)	PC > DC > CDE > SE
	MCDM (dominance)	PC > DC > CDE > SE
Fully cooperative (Rastgoftar et al. 2012)	Fuzzy (centroid deffuzification)	PC > DC > SE > CDE

Delta's decision makers. Under the fully non-cooperative case, which has been the status of the problem for decades, CDE is the most likely equilibrium of the game, i.e. water export will continue using the existing water export facilities. However, once the parties decide to change their cooperation strategies, even low levels of cooperation can result in CDE becoming an inferior and less likely outcome. Under cooperation, PC and DC are the most likely resolutions of the Delta's conflict.

11.4 Conclusions

This study suggested a method for analyzing bargaining problems in which the parties are uncertain about the performance of alternative bargaining outcomes. The suggested method ranks the likely outcomes of the bargaining process and determines the ranking robustness. To show the usefulness of the suggested method, this method was applied to solve the Sacramento-San Joaquin's Delta conflict as a benchmark stochastic multi-decision maker problem. To explore the most likely outcomes of this problem in which parties have to agree over an alternative for continuation of water export from the Delta, this problem was modeled as a bargaining procedure in which two bargainers, representing the main Delta interests, have to reach an agreement over a water export alternative. Three different FB methods were used to solve the benchmark problem. Given that the Delta problem has only two main decision makers, the q-approval FB method was not found to be appropriate. Nevertheless, this method is applicable in bargaining problems that involve more decision makers.

Overall the results suggest that building a peripheral canal or dual conveyance system are the most likely and robust outcomes of the Delta problem if the decision were to be made through bargaining. When parties are allowed to choose no-agreement as an additional option, selection of this option is more likely than continuation of water export as usual or stopping delta export. Findings of the study were consistent with those of previous studies of the Delta benchmark problem that used different decision analysis methods. Results suggest that except a fully non-cooperative case, which results in no resolution or in continuation of the status quo, building a peripheral canal or dual conveyance is likely in other cases, even if the level of cooperation among stakeholders is low.

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Chapter 12
A Decision Support System for Solving the Conflict Between Human and Environment

Ju Jiang, Haiyan Xu and Yangzi Jiang

Abstract A new decision support system based on matrix representation for conflict resolution under three-degree preference is designed for analyzing and solving conflict in practice. Because decision and negotiation are common but important human activity, there is a great need for a flexible decision support system that can systematically investigate a wide range of real-world strategic conflicts. The decision support system GMCR II, based on logical representations, is capable of handling two-degree preference only. However, the two-degree structure is limited in its ability to depict the intensity of relative preference. The proposed decision support system may deal with more complex strategic conflicts such as conflict with three-degree preference. The new system is illustrated in this paper using an international environmental dispute that was resulted from the environmental pollution among US, Canada, and International Joint Commission. To irrigate land in the northeastern section of North Dakota, an irrigation project was proposed by the United States Support (USS) regarding construction of a canal and holding reservoir to transfer water from the Missouri River Basin to the Hudson Bay Basin. Due to different goals, the Garrison Diversion Unit (GDU) conflict arose among US, Canada, and International Joint Commission. The resolution to solve this conflict is suggested by the new decision support system.

Keywords Decision support system · Conflict analysis · Matrix representation for conflict resolution · Three-degree preference · Stability analysis

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_12

12.1 Introduction

In a water quality dispute, an environmental agency may greatly prefer that an industrial enterprise does not seriously pollute a nearby river into which it discharges wastes. Therefore, this type of "degree", "strength", or "level" of preference often arises in practice in order to determine strategic consequences. Specifically, a three-degree preference structure is introduced in this paper within the paradigm of the Graph Model for Conflict Resolution (GMCR) (Fang et al. 1993) in conjunction with an associated decision support system (DSS) to calculate stabilities of each state from a given decision maker's (DM's) viewpoint as well as the overall equilibria using a matrix approach.

The purpose of this paper is to develop a DSS based on a formal methodology that can handle the conflicts under three-degree preference, which often arises in practice. A two degrees of preference structure called a simple preference contains two types of preferences: indifference, indicating that a DM is indifferent between two states, and strict preference, in which the DM prefers one state to another (Fang et al. 1993). The third kind of preference can be added into the DSS by allowing a DM to greatly prefer one state to another (Hamouda et al. 2004, 2006). The paradigm of the GMCR is to calculate stabilities for solving and analyzing conflicts based on a logical form. The logical version of the four basic stabilities including Nash stability (Nash 1950, 1951), general metarationality (GMR), symmetric metarationality (SMR) (Howard 1971), and sequential stability (SEQ) (Fraser and Hipel 1979) often require extensive calculations and are difficult to code. Particularly, the construction of reachable lists is a complicated process (Fang et al. 1993) when the number of DMs is more than two in stability analysis. To analyze complex conflicts efficiently and expeditiously, an algorithm to implement these stabilities, along with a decision support system, would be extremely valuable. Although DSS GMCR II is available for the four basic stabilities, it is capable of handling two-degree preference only (Fang et al. 2003a, b). Difficulties in coding algorithms to analyze stabilities because of logical representation, led to the development of a matrix version for conflict resolution.

Matrix representations for conflict resolution (MRCR) for a graph model have been developed for two-degree preference (Xu et al. 2009), unknown preference (Xu et al. 2011), and for three degrees of preference (Haiyan et al. 2010). Due to the nature of the explicit algebraic expressions, the matrix method is more effective, convenient, flexible, and extendable than existing approaches in terms of the underlying graphs and the logical expressions. Xu et al. (2009, 2010, 2011), Haiyan et al. (2010) have shown advantages of using matrix approaches to calculate potential resolutions, track conflict evolution based on status quo analysis (Li et al. 2005), and carry out coalitional stability analysis (Inohara and Hipel 2008). As shown in Table 12.1, compared with GMCR II, the DSS based on MRCR, called MRCRDSS, can handle more conflict problems for various preference structures such as two-degree of preference and three degrees of preference. The aforementioned two-level structure is limited in its ability to depict the intensity of

Table 12.1 Comparison of MRCRDSS with GMCR II

Preference information	Stability and post-stability analyses	In MRCRDSS?	In GMCR II?
Two degrees of preference	Individual stability analysis	Yes	Yes
	Status quo analysis	Yes	Yes
	Coalition stability analysis	Yes	No
Three degrees of preference	Individual stability analysis	Yes	No
	Status quo analysis	Yes	No
	Coalition stability analysis	Yes	No

relative preference. For example, DMs often exhibit strong preference which may affect their behavior, such as in an environmental dispute where environmentalists very strongly prefer that a development project not proceed if it will cause significant harm to the local ecosystem. Thus, a preference framework called "strength of preference" was developed (Hamouda et al. 2004, 2006). It includes two new binary relations, greatly preferred, denoted by $\gg$, and mildly preferred, written as $>$, expressing a DM's strong or mild preference for one state over another. When these are combined with the indifference relation $\sim$, a three-degree preference structure is formed. The three-degree preference structure is included into MRCRDSS in this paper to provide highly informative strategic results for DMs.

Several important definitions corresponding to logical and matrix representations for conflict resolution in the graph model are presented in Sect. 12.2, followed by the development of MRCRDSS under three-degree preference in Sect. 12.3. Within Sect. 12.4, the proposed MRCRDSS is employed to analyze the Garrison Diversion Unit (GDU) conflict including three degrees of preference. Finally, some conclusions and ideas for future work are provided in Sect. 12.5.

12.2 Background of Graph Model for Conflict Resolution with Three-Degree Preference

12.2.1 The Graph Model with Three Degrees of Preference

As depicted in Fig. 12.1, many models are available for describing strategic conflicts, such as in the left branch of Fig. 12.1, metagame analysis employs option form (Howard 1971) for recording a conflict, while in the right branch, normal form is often written using a tabular or matrix format for the case of two DMs. For GMCR listed at the bottom of the left branch in Fig. 12.1, the movements in one step by a given DM are captured within a directed graph for that DM.

A triplet relation on S that expresses strength of preference according to indifferent, mild, or strong preference, was developed by Hamouda et al. (2004, 2006). For states $s, q \in S$, the preference relation $s \sim_i q$ indicates that DM i is indifferent (or equal) between states s and q, the relation $s >_i q$ means that DM i mildly prefers s to q, and $s \gg_i q$ denotes that DM i strongly prefers s to q. The properties

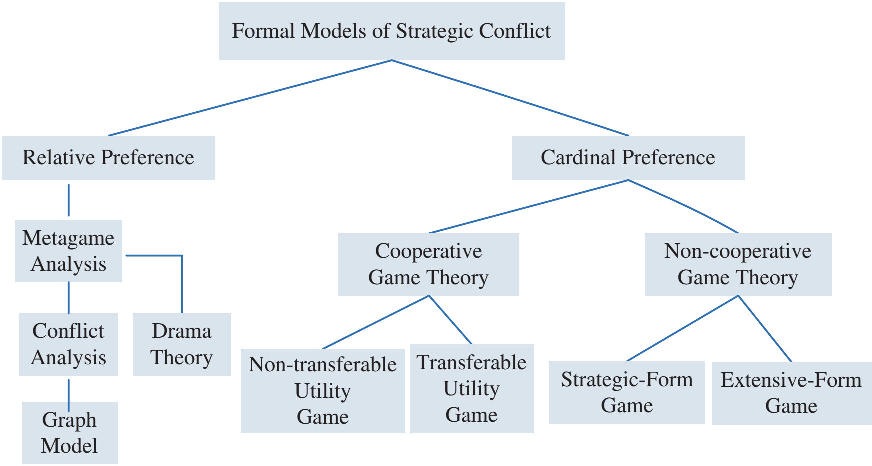

Fig. 12.1 The genealogy of conflict models

of the preference structure, $\{\sim_i, >_i, \gg_i\}$, containing three kinds of preference for each DM $i \in N$ are as follows:

(i) $\sim_i$ is reflexive and symmetric;
(ii) $>_i$ and $\gg_i$ are asymmetric; and
(iii) $\{\sim_i, >_i, \gg_i\}$ is strongly complete.

Note that $\{\sim_i, >_i, \gg_i\}$ is strongly complete. Hence, if $s, q \in S$, then exactly one of the following relations holds: $s \sim_i q, s >_i q, s \gg_i q, q >_i s$, or $q \gg_i s$. Also, it is assumed that, for any $s, q \in S, s >_i q$ is equivalent to $q <_i s$. The preference type "$\gg_i$" has similar properties to "$>_i$".

A graph model under three-degree preference is a structure $G = \langle N, S, \{\gg_i, >_i, \sim_i\}_{i \in N}, \{(S, A_i)\}_{i \in N}$ in which N is a non-empty set of DMs, S is a non-empty set of states, for each DM $i \in N$, $\{\gg_i, >_i, \sim_i\}_{i \in N}$ is DM i's three degrees of preference on $S, A_i \subseteq S \times S$ is DM i's oriented arcs, and $G_i = (S, A_i)$ is i's directed graph. Obviously, preference is an essential component for a graph model. The original graph model uses a "two-degree preference structure $\{\succ, \sim\}$" to represent a DM's relative preference relation "$\succ$" and an indifference relation "$\sim$" between two states. In the graph model with three-level preference, $s \succ_i q$ iff either $s >_i q$ or $s \gg_i q$ for $s, q \in S$. Therefore, three-degree preference expands two degrees of preference.

12.2.2 *Reachable Lists for Three Degrees of Preference*

The reachable lists of a DM for three types of preference are defined as follows:

(i) $R_i(s) = \{q \in S : (s, q) \in A_i\}$ stands for DM i's reachable list from state s by a unilateral move (UM);

(ii) $R_i^{+}(s) = \{q \in S : (s, q) \in A_i \text{ and } q >_i s\}$ denotes DM i's reachable list from state s by a mild unilateral improvement;

(iii) $R_i^{++}(s) = \{q \in S : (s, q) \in A_i \text{ and } q \gg_i s\}$ stands for DM i's reachable list from state s by a strong unilateral improvement. This set contains all states q which are strongly preferred by DM i to state s and can be reached in one step from s;

(iv) $R_i^{+,++}(s) = R_i^{+}(s) \cup R_i^{++}(s) = \{q \in S : (s, q) \in A_i \text{ and } q >_i s \text{ or } q \gg_i s\}$ denotes DM i's reachable list from state s by a mild unilateral move or strong unilateral move (MSUM);

(v) $R_H(s)$ stands for the reachable list of coalition H from state s by a legal sequence of UMs;

(vi) $R_H^{+,++}(s)$ stands for the reachable list of coalition H from state s by a legal sequence of MSUMs.

12.2.3 Matrix Representation for Conflict Resolution with Three-Degree Preference

Because a graph model of a conflict consists of several interrelated graphs, it is natural to use results of Algebraic Graph Theory to help analyze a graph model. It is well-known that any graph is equivalent to a matrix. The logical representation of the Nash, GMR, SMR, and SEQ, for three-degree preference in GMCR can be represented in matrix forms. The components of the matrix representation for conflict resolution are presented as follows.

12.2.3.1 Several Important Matrices

Firstly, define DM i's preference matrices P_i^{++} and P_i^{--} by

$$P_i^{++}(s, q) = \begin{cases} 1 & \textit{if } q \gg_i s, \\ 0 & \textit{otherwise}, \end{cases} \quad P_i^{--}(s, q) = \begin{cases} 1 & \textit{if } s \gg_i q, \\ 0 & \textit{otherwise}. \end{cases} \tag{12.1}$$

Let N denote the set of DMs, $|N| = n$ is the number of DMs, and m stand for the number of states. After obtaining the preference matrices, the matrix representation of the reachable lists is given by Table 12.2 in which all of matrices are $m \times m$ matrices.

The four basic stability definitions, Nash, GMR, SMR, and SEQ, for three-degree preference recognize two cases in which the degree of strength in the three kinds of preference are distinguished. Firstly, general stabilities are defined, and then the two subclasses, strong and weak, are determined (Hamouda et al. 2004, 2006). Stabilities of the the first kind are referred to as general because they are in essence the same as the stability definitions using two-degree preference. Stability definitions are called strong or weak stabilities in order to reflect the additional preference information contained in the strength of the preference relation.

Table 12.2 The important matrices related to this research

Notation	Matrices	Description
Adjacency matrix	J_i	The sth row of J_i is equivalent to $R_i(s)$
	$J_i^{+,++}$	The sth row of $J_i^{+,++}$ is equivalent to $R_i^{+,++}(s)$
Preference matrix	$P_i^{--,-,=}$	$P_i^{--,-,=} = E - P_i^{++} - I$
	P_i^{--}	See Eq. 12.1
	P_i^{++}	See Eq. 12.1
Reachability matrix	M_{N-i}	The sth row of M_{N-i} is equivalent to $R_{N-i}(s)$
	$M_{N-i}^{+,++}$	The sth row of $M_{N-i}^{+,++}$ is equivalent to $R_{N-i}^{+,++}(s)$
Special matrix	I	The identical matrix
	E	Each entry with 1

Let GS denote a graph model stability, Nash, GMR, SMR, or SEQ. The symbols GGS, SGS, and WGS respectively represent a general stability, GNash, GGMR, GSMR, or GSEQ, the strong stability, SGMR, SSMR, or SSEQ, and the weak stability, WGMR, WSMR, or WSEQ, under three degrees of preference. M_i^{GGS} and M_i^{SGS} denote DM i's general stability matrix, M_i^{GNash}, M_i^{GGMR}, M_i^{GSMR}, or M_i^{GSEQ}, and DM i's strong stability matrix, M_i^{SGMR}, M_i^{SSMR}, or M_i^{SSEQ}, respectively.

Based on the stability matrices M_i^{GGS} and M_i^{SGS} shown in Table 12.3, the stabilities under three-degree preference are calculated using the following theorems. [Note that all of components in Table 12.3 is defined in the paper (Haiyan et al. 2010).]

Theorem 1 *State $s \in S$ is GGS stable for DM i iff the diagonal entry of the matrix M_i^{GGS} at (s, s) is zero, i.e., $M_i^{GGS}(s, s) = 0$.*

Theorem 1 contains four results because $M_i^{GGS}(s, s) = 0$ means $M_i^{GNash}(s, s) = 0$, $M_i^{GGMR}(s, s) = 0$, $M_i^{GSMR}(s, s) = 0$, or $M_i^{GSEQ}(s, s) = 0$. The above matrix method, called matrix representation of general stability, is equivalent to the logical representation for general stability given in (Hamouda et al. 2004, 2006). To analyze general stability of state s for DM i, one only needs to check if the entry, $M_i^{GGS}(s, s)$, in the stability matrix is zero. If so, state s is general stable for i; otherwise, s is general unstable for DM i. Note that all information about general stability is contained in the diagonal entries of the general matrix.

Similarly, we have the strong stability result as follows.

Theorem 2 *State $s \in S$ is SGS stable for DM i iff the diagonal entry of the matrix M_i^{SGS} at (s, s) is zero, i.e., $M_i^{SGS}(s, s) = 0$.*

Theorem 2 contains three results because $M_i^{SGS}(s, s) = 0$ means $M_i^{SGMR}(s, s) = 0$, $M_i^{SSMR}(s, s) = 0$, or $M_i^{SSEQ}(s, s) = 0$.

Based on the notation presented above, one has the following definition.

Definition 1 State $s \in S$ is weak stable (WGS) for DM i iff $M_i^{GGS}(s, s) = 0$, but $M_i^{SGS}(s, s) \neq 0$.

Table 12.3 Construction of stability matrices under three-degree preference

Preference	Definition set	Stability matrices
Three degrees of preference	General stabilities	$M_i^{GNash} = J_i^{+,++} \cdot E$
		$M_i^{GGMR} = J_i^{+,++} \cdot \left[E - sign\left(M_{N-i} \cdot (P_i^{--,-,=})^T\right)\right]$
		$M_i^{GSMR} = J_i^{+,++} \cdot \left[E - sign(M_{N-i} \cdot Q)\right]$, with $Q = (P_i^{--,-,=})^T \circ [E - sign(J_i \cdot (P_i^{+,++})^T)]$
		$M_i^{GSEQ} = J_i^{+,++} \cdot [E - sign\left(M_{N-i}^{+,++} \cdot (P_i^{--,-,=})^T\right)]$
	Strong stabilities	$M_i^{SGMR} = J_i^{+,++} \cdot [E - sign\left(M_{N-i} \cdot (P_i^{--})^T\right)]$
		$M_i^{SSMR} = J_i^{+,++} \cdot [E - sign(M_{N-i} \cdot F)]$, with $F = P_i^{++} \circ [E - sign(J_i \cdot P_i^{++})]$
		$M_i^{SSEQ} = J_i^{+,++} \cdot [E - sign\left(M_{N-i}^{+,++} \cdot (P_i^{--})^T\right)]$

Definition 1 means that if s is general stable, but not strong stable for a stability GS, then s is weak stable for the stability GS. Usually, one focuses on the discussion for general stability and strong stability as shown in this paper.

12.3 DSS Based on Matrix Representation for Conflict Resolution

Although GMCR has many advantages, it is difficult to apply in real problems without computational assistance, even to small models. With this purpose, the basic decision support system GMCR II written in Visual C++, a computer implementation of the graph model for conflict resolution, was developed by Fang et al. (2003a, b). GMCR II can analyze stabilities for simple preference and make basic status quo analysis and coalitional analysis. However, as was noted in the development of GMCR II, the nature of logical representations makes coding difficult to modify and extend so that new analysis techniques cannot be easily integrated into it. Within the design for the new MRCRDSS that is based on matrix representation for conflict resolution, MFC Class library of Visual C++, one of important visual programming tools, is selected to code this user interface for this DSS. The main algorithm based on MRCR is coded using Matlab. The connection between Visual C++ and Matlab programs is achieved by MatcomV4.5, which is a mixed programming software. Until now, the main functions of MRCRDSS developed are described in Fig. 12.2, which includes stability analysis under two-degree preference (simple preference), unknown preference (uncertain preference), and three degrees of preference (strength of preference). The MRCRDSS is applied to a graph model with three degrees of preference in this research.

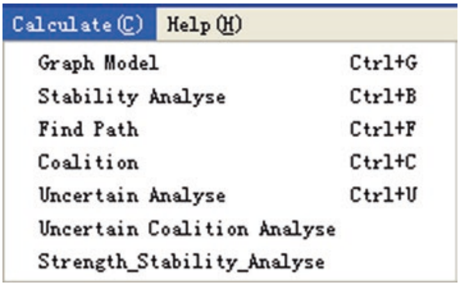

Fig. 12.2 The function menu of MRCRDSS

The main procedures of MRCRDSS are as follows:

1. Input the names and options of DMs to create all possible states, and then delete the infeasible;
2. Input each DM's preference over the feasible states;
3. Input each DM's reachable list over the feasible states;
4. Create a graph model for a conflict using available input information from (1) to (3), as shown in Fig. 12.3 in which different DMs are presented as different colors;
5. Output the stability result under some preference;
6. Present the evolutionary pathes from any start state to an equilibrium using status quo analysis.

The proposed MRCRDSS is employed in the following case, the Garrison Diversion Unit (GDU) conflict, under three-degree preference.

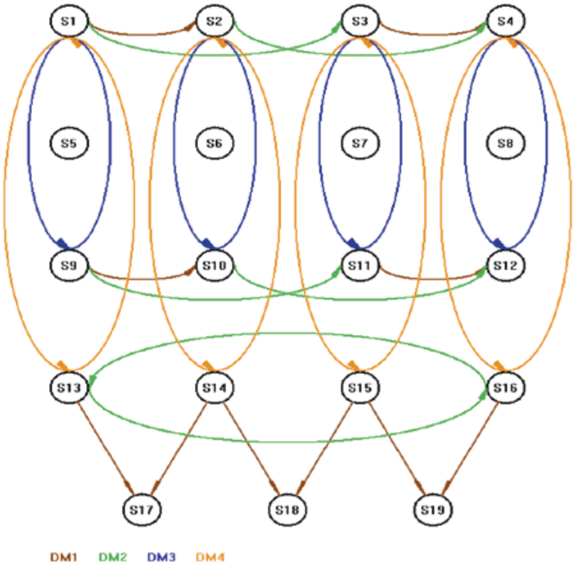

Fig. 12.3 A graph model created by MRCRDSS

12.4 Application of MRCRDSS

12.4.1 The Garrison Diversion Unit (GDU) Model

In this section, the three-degree versions of stability definitions are applied to the Garrison Diversion Unit (GDU) conflict to illustrate how the procedure works. The history of this conflict dates back to the nineteenth century. In order to irrigate land in the northeastern section of North Dakota, an irrigation project was proposed by the **United States Support (USS)** regarding construction of a crucial canal and holding reservoir to transfer water from the Missouri River Basin to the Hudson Bay Basin (Fang et al. 1993). Because the irrigation run-off finally flow into the Canadian province of Manitoba via the Red and Souris rivers, which will cause environmental damage, this proposal immediately aroused the **Canadian Opposition (CDO)**. In order to resolve this conflict, the **International Joint Commission (IJC)** consisting of representatives from the governments of USA and Canada plays an important role for taking an unbiased attitude and making recommendations on this project (Fang et al. 1993; Hamouda et al. 2006). This irrigation project for the water diversion is called the Garrison Diversion Unit (GDU) project. A conflict arose among US, Canada and IJC for the GDU project (see the book (Fang et al. 1993) and the paper (Hamouda et al. 2006) for more details). The three DMs' options are presented as follows.

- The US Support's options: 1. **Proceed** (or not) with the project regardless of Canada's concerns, and
- 2. **Modify** (or not) the project to reduce impacts in Canada;
- The Canadian Opposition's option: 3. Initiate **legal** action based on the Boundary Waters Treaty or not;
- The International Joint Commission's options: 4. Recommend **completion** (or not) of project as originally planned, and
- 5. Recommend **modification** (or not) of the project to reduce impacts on Canada.

A state is defined as a feasible selection of options by each DM. In the GDU model, the five options combine to form $2^5 = 32$ possible states in principle. Usually, however, not all option combinations are feasible or logical. In the GDU model, after all infeasible states were eliminated, only 9 feasible states remained; they are listed in Table 12.4, where a "Y" indicates that an option is selected by the DM controlling it, and an "N" means that the option is not chosen.

The three-degree preference information for this conflict over the feasible states is given in Table 12.5. We assume that state s_8 is strongly less preferred to all other states for USS, and the DM, CDO considers states s_1, s_2, and s_6 to be equally preferred and strongly less preferred relative to all other states. Note that this representation of preference information presented in Table 12.5 implies that the preferred relations, $>$ and $\gg$ are transitive.

Table 12.4 Feasible states for the GDU model

USS									
1. Proceed	Y	Y	N	Y	N	Y	N	Y	N
2. Modify	N	N	Y	N	Y	N	Y	N	Y
CDO									
3. Legal	N	N	N	Y	Y	N	N	Y	Y
IJC									
4. Completion	N	Y	Y	Y	Y	N	N	N	N
5. Modification	N	N	N	N	N	Y	Y	Y	Y
State number	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9

Table 12.5 Relative preferences for DMs in the GDU conflict (Hamouda et al. 2006)

DM	Preference
USS	$s_2 > s_4 > s_3 > s_5 > s_1 > s_6 > s_9 > s_7 \gg s_8$
CDO	$\{s_3 \sim s_7\} > \{s_5 \sim s_9\} > \{s_4 \sim s_8\} \gg \{s_1 \sim s_2 \sim s_6\}$
IJC	$\{s_2 \sim s_3 \sim s_4 \sim s_5 \sim s_6 \sim s_7 \sim s_8 \sim s_9\} > s_1$

12.4.2 The Procedures Using MRCRDSS

The main procedures of resolving the GDU conflict using MRCRDSS are as follows:

1. Input the names and options of three DMs of the GDU conflict into MRCRDSS to obtain all possible states, delete the infeasible states, and then create the feasible states presented in Fig. 12.4;
2. Create the graph model of the GDU model shown in Fig. 12.5, in which the color of the arc indicates the DM who controls the move;
3. Input each DM's preference of the GDU model over the feasible states into MRCRDSS (see Fig. 12.6);
4. Output the stability result of the GDU model shown in Fig. 12.7 with three-degree preference;
5. Present the evolutionary pathes for the GDU conflict presented in Fig. 12.7 from state s_1 to the equilibrium s_4 using status quo analysis.

The remaining analysis requirement for a graph model is knowledge of each DM's preference ranking of the feasible states. The preference information for the GDU model over the feasible states given in Table 12.5 is equivalent to preferences presented in Fig. 12.6. For example, USS's preference $s_2 > s_4 > s_3 > s_5 > s_1 > s_6 > s_9 > s_7$ can be expressed as $P(s_2) = 10 > P(s_4) = 9 > P(s_3) = 8 > P(s_5) = 7 > P(s_1) = 6 > P(s_6) = 5 > P(s_9) = 4 > P(s_7) = 3$ that are input to MRCRDSS. Since $s_7 \gg s_8$, then $P(s_7) = 3 \gg P(s_8) = 1$ is input to MRCRDSS. Similarly, the three-level preferences for the three DMs are input to this system as presented in Fig. 12.6.

After all of information is input, the stability result including general and strong stabilities of the GDU conflict is output in Fig. 12.7 using the MRCRDSS. Note that the notation of general stabilities, GNash, GGMR, GSMR, and GSEQ,

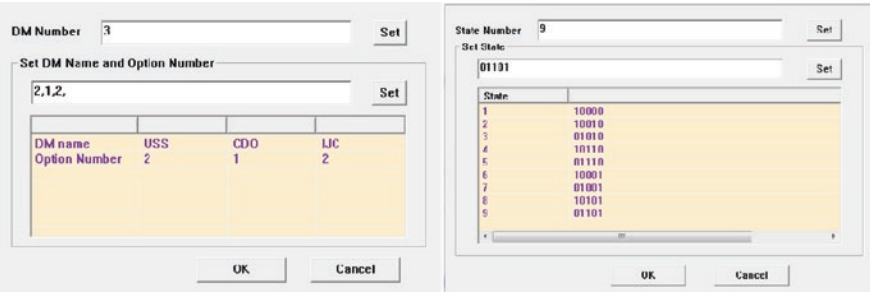

Fig. 12.4 The DMs, options, and states for GDU conflict

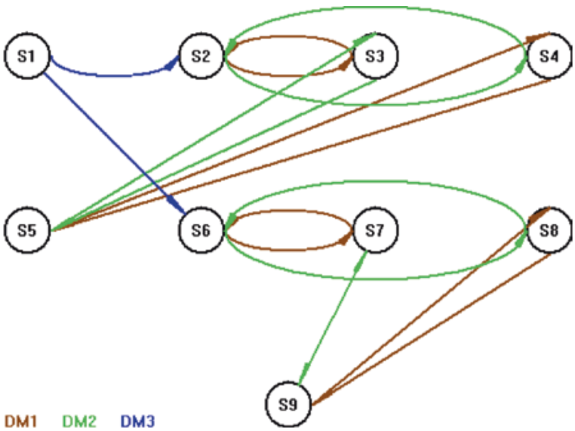

Fig. 12.5 The graph model for GDU conflict

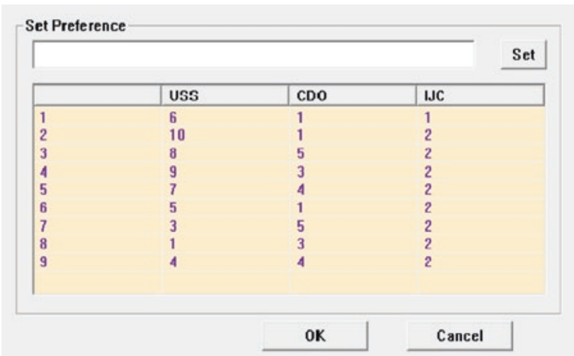

Fig. 12.6 Three-degree preference for GDU conflict

State Graph and Equilibrium :

State	USS		CDO		IJC		Equilibrium				Strength		
	R	P	R	P	R	P	Nash	GMR	SMR	SEQ	SGMR	SSMR	SSEQ
1	0	6	0	1	2,6	1							
2	3	10	4	1	0	2							
3	2	8	5	5	0	2							
4	5	9	2	3	0	2	√	√	√	√	√	√	√
5	4	7	3	4	0	2							
6	7	5	8	1	0	2							
7	6	3	9	5	0	2		√		√	√		√
8	9	1	6	3	0	2							
9	8	4	7	4	0	2		√	√	√	√	√	√

Path: =======> USS; =======> CDO; =======> IJC;

Fig. 12.7 Stability result of the GDU conflict

is output using Nash, GMR, SMR, and SEQ, which are the same as that of simple preference. The strong stabilities are presented by SGMR, SSMR, and SSEQ as shown the right three columns in Fig. 12.7. The stability results for the GDU conflict are summarized in Fig. 12.7, in which "√" for a given state under a DM means that this state is general stable or strong stable for the given DM. The results presented in Fig. 12.7 are identical with that in (Hamouda et al. 2006) using logical representation. The information including strength of preference is input into MRCRDSS and then is converted to the form presented in the left of Fig. 12.7 in the "P" columns that is the same as the result presented in Fig. 12.6. Notation "R" in Fig. 12.7 denotes the reachable list from a state. Two evolutionary paths from an initial state s_1 to the equilibrium s_4 are output below the stability result in Fig. 12.7.

12.5 Conclusions and Future Work

A decision support system based on matrix representation for conflict resolution (MRCRDSS) under three degrees of preference is proposed in this paper for systematically investigating a wide range of real-world strategic conflicts. Compared with existing DSS, GMCR II that can deal with conflicts with two-degree preference only, MRCRDSS is more effective and has wider realm of applicability in real world conflicts. Therefore, more practical and complicated problems can be analyzed at greater depth using the new system.

In future, the system MRCRDSS will be expanded to model and analyze the conflicts including hybrid preference of uncertainty and strength. An integrated DSS including stability analysis under hybrid preference of uncertainty and strength, status quo analysis, and coalitional stability analysis would be very useful.

Acknowledgment We appreciate the support from the Foundation of Universities in Jiangsu for Philosophy and Social Sciences (2012ZDIXM014) and the National Natural Science Foundation of China (NSFC) (71471087).

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Chapter 13
CAPE WIND: Offshore Renewable Energy Conflict

Mary Jo Larson

Abstract Water, environment and energy conflicts are particularly complex—easy to distort and difficult to resolve. The Cape Wind conflict, which began in 2001 over plans to develop the first offshore wind farm in the United States (US), has been complicated by the incompatible interests and power dynamics of multiple parties, scientific uncertainty, and the requirements of national, state and local government jurisdictions. This paper analyses the first phase of the protracted negotiations. It draws lessons from the author's book project on the Cape Wind conflict (upcoming 2015). The research objective is to develop user-friendly techniques and tools for mapping not only the power dynamics of environmental negotiations over time but also the "turning point" influences of high power stakeholders and external factors, such as environmental catastrophes, political outcomes and technical innovations.

Keywords Multilateral negotiation · Timing · Turning point

13.1 Introduction

"Cape Wind" is the first offshore wind farm proposed in the United States (US). The planned facility will be located approximately five miles from Cape Cod's mainland resort towns, nine miles from Martha's Vineyard and 13 miles from Nantucket Island. In 2001, when Cape Wind Associates, LLC first released plans to construct wind turbines off the shores of Cape Cod, the estimated cost was $600 million. By December 2014, following over 13 years of opposition through media campaigns, legal and regulatory delays, the estimated cost for 130 wind turbines had escalated to over $2.6 billion (Goossens 2013).

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_13

The focal point of the Cape Wind conflict is Nantucket Sound, a roughly triangular area of the Atlantic Ocean located between the Cape Cod mainland and two resort islands: Martha's Vineyard and Nantucket Island. The proposed location for the turbines, based on wind energy assessments, is a shallow area of the Sound called Horseshoe Shoal. The federal government of the United States (US) has primary jurisdiction over this site, as it is located more than three nautical miles off the shores of the Commonwealth of Massachusetts (MA).[1]

Opponents of the project argue that Nantucket Sound is a "national treasure" with particular significance for species of federally protected wildlife, commercial and recreational fishing, tourism and recreational boating. This body of water is the site of the annual Figawi Race Weekend, recognized as a top sailing event nationally and internationally. The scenic Cape Cod towns and views along the Sound's coastline have attracted generations of summer vacationers and prominent US residents, including the family of former President John F. Kennedy. Waterfront property is highly valued in MA, and especially in the resort areas of Cape Cod, as residents enjoy private access to non-public beaches and unobstructed ocean views.[2]

Efforts to construct the Cape Wind facility in Nantucket Sound have been complicated and delayed by the power dynamics of private, independent and public sector stakeholders. Prominent opponents of the project have included Senator Edward M. Kennedy (Democrat (D)-MA), Governor W. Mitt Romney (Republican (R)-MA, 2003–2007), MA Attorney General Tom Reilly (D-MA, 1999–2007), Sen. Trent Lott (R-Mississippi), Sen. John Warner (R-Virginia), Rachel "Bunny" Lambert Mellon (father commercialized Listerine), William I. Koch (Oxbow Group), Richard J. Egan (EMC Corp.), Paul Fireman (Reebock), William Delahunt, (D-MA), and Robert F. Kennedy, Jr.

In the US, debate over the construction of this offshore renewable energy facility has been framed through the lens of energy innovation, sustainability of New England's maritime traditions and heritage, US energy security, the preservation of region's tribal cultures and archaeology, and beliefs about global climate change.

This analysis of the Cape Wind case contributes, in theory and practice, to understandings of the psychological, structural and material roots of environmental conflicts (Galtung 1996). Conflict analysis tools seek levels of flexibility[3] and map the dynamics of the protracted negotiations (Larson 2003). A unique feature

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[1] Pursuant to Proclamation No. 5030, the US federal government has jurisdiction over the living and non-living resources from three to 200 nautical miles off US coastal shores.

[2] By law, private property on the coasts of MA extend to the mean *low*-tide mark, as opposed to the *high-tide* mark applied in most US jurisdictions.

[3] In environmental negotiations, "flexibility" is defined as the stakeholders' willingness and ability to adapt to changes within subsystems and the ecological system as a whole. Integrative relationships, such as collaboration, cooperation, coordination and competition are indicators of flexibility. Aggression and avoidance are indicators of inflexibility (Larson 2003).

of this study is the identification and visual explanation of turning points, which are the significant ideas, actions or events indicating movement toward or away from an integrative (win/win) resolution of a conflict (Druckman 2001).

In theory, *flexibility* is at the heart of any conflict resolution process. An inclusive, integrative approach ensures that vulnerable stakeholders are fairly represented in the negotiations (Larson 2001). In conflicts that involve an environmental resource, such as a body of water, stakeholders are willing to learn and adapt as they navigate toward a common overarching goal related to sustainability or "sustainable development."[4]

In reality, psychological factors, such as people's beliefs, values and intentions, complicate environmental negotiations. Status defense and similar theories indicate that high power groups may not be willing to engage in the give and take associated with flexible, constructive problem solving (Clements 2004).

In the following pages, this analysis concentrates on the first 2 years of the protracted Cape Wind conflict. The study includes a description of stakeholders, including high power actors and their negotiation dynamics. A turning point matrix, which divides this environmental conflict into four phases, helps to illustrate the negotiation process and outcomes.

13.2 Cape Wind Stakeholders

The Cape Wind controversy involves public, private and independent stakeholders with mixed motives, shared concerns and contradictory interests. Two powerful adversaries in this conflict are Cape Wind Associates, LLC and the Alliance to Protect Nantucket Sound. As described below, other stakeholders include local fishermen, full-time and summer residents of Cape Cod, and citizens affected by the federal, state and local regulations and policies.

Cape Wind Associates, LLC ("Cape Wind") is the private sector developer of the proposed wind farm. In 2001, James "Jim" Gordon formed the company in partnership with Brian Braginton-Smith, who first conceived of the Cape Cod wind farm, and a third partner, Brian Caffyn, who had previous experience developing wind farms in Italy. The developers are convinced that clean, renewable wind energy will stabilize Cape Cod's long-term energy costs, contribute to US energy security, and mitigate the threats of climate change.

Jim Gordon was one of first entrepreneurs to benefit from deregulation of the power market in the US. In 1975, Gordon founded Energy Management Incorporated (EMI), a Boston-based company specializing in energy-efficient power plants and technologies. In 2000, EMI sold its interests in five New England power plants for an estimated $250 million (Krasner 2001). Gordon, who

[4] Sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Definition crafted by World Commission on Environment and Development (Brundtland Commission 1987).

describes himself as "careful and deliberate," was soon attracted to the economic, social and environmental benefits of Cape Cod's clean, renewable offshore wind power potential (Larson 2011, 2014).

According to the Cape Wind website available at http://www.capewind.org/ (Cape Wind 2014):

- Cape Cod has the worst air quality in the Commonwealth of Massachusetts (citing American Lung Association).
- Cape Wind will produce up to 420 megawatts of clean, renewable energy.
- The clean energy produced by Cape Wind will reduce the region's greenhouse gas emissions by 734,000 tons per year.
- Cape Wind will create nearly a thousand jobs in assembly and offshore construction and create 150 permanent jobs, including 50 highly paid maintenance and operations jobs based in Cape Cod.

Why did Cape Wind choose the shallow waters within Nantucket Sound for this offshore energy facility? The Cape Wind website explains why the 24-square mile area of Nantucket Sound (called Horseshoe Shoal) is the best site for the wind farm. Reasons for establishing the nation's first wind energy project in this shoal of Nantucket Sound include (Cape Wind 2008–2014):

- Horseshoe Shoal, the largest of many shoals within Nantucket Sound, offers one of the top two offshore wind energy resources on the Atlantic Seaboard.
- Of 17 New England sites evaluated by the U.S. Army Corps of Engineers and Department of Energy: Energy Efficiency and Renewable Energy, Horseshoe Shoal meets three criteria:
  - Strong wind resource
  - Shallow depth (generally less than 45'); tall turbines easier to build
  - Low ocean storm wave heights

The U.S. Department of Energy produced a 50-m height wind resource map for Massachusetts to illustrate the state's wind resource potential from a policy and economic development perspective (US Department of Energy 2014).[5] The map (Fig. 13.1) shows the state' offshore wind resource potential. On a scale of 1–7, Nantucket Sound's wind power (wind speed frequency distributions and air density) is classified 6 "Outstanding" (color code red) with some areas close to the coast rated 5 "Excellent."

Cape Wind is one of the largest greenhouse gas reduction initiatives proposed in the U.S. In average winds, the project will generate enough power to meet 75 % of the electricity demands for Cape Cod, Martha's Vineyard and Nantucket Island combined.

Prominent supporters of the Cape Wind project have included MA Governor Deval Patrick, who declared his support of the project in 2005 (while still a candidate); Barnstable Representative Matthew Patrick (D-MA), Senator Olympia

[5] U.S. Department of Energy: Energy Efficiency and Renewable Energy works are public domain (http://www1.eere.energy.gov/webpolicies/#copyright) For a PDF color copy of the map see: http://apps2.eere.energy.gov/wind/windexchange/maps_template.asp?stateab=ma.

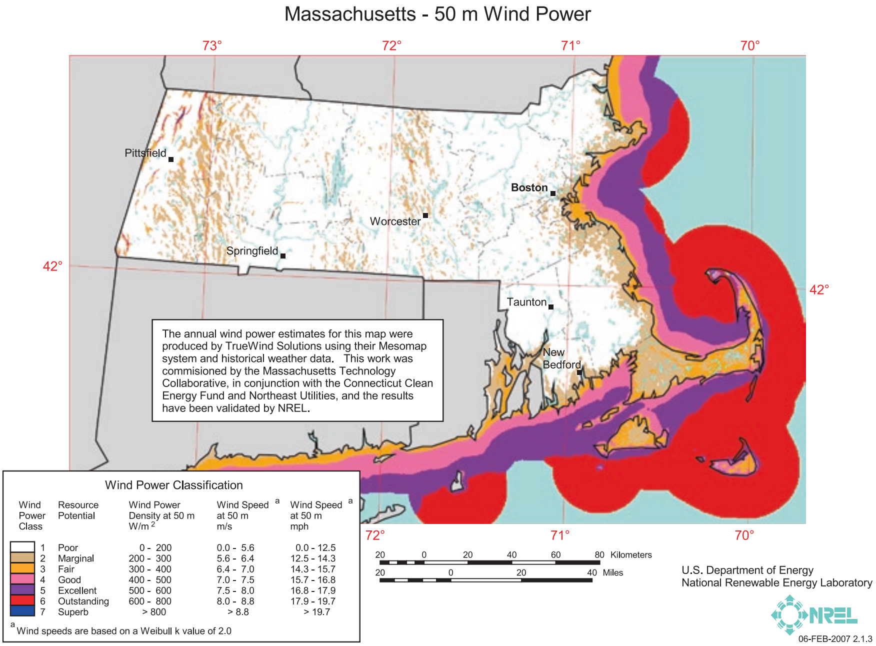

Fig. 13.1 Offshore wind energy resources in Massachusetts

Snowe (R-Maine), Representative Jim Bass (R-New Hampshire), Senator John McCain (R-Arizona), Senator Jeff Bingaman (D-New Mexico (NM)), Senator Pete Domenici (R-NM), and Theodore Roosevelt, IV (Furman 2011).

13.2.1 The Alliance to Protect Nantucket Sound

In July 2001, news of the proposed offshore wind farm in a *Boston Globe* newspaper article (Krasner 2001) triggered a focused, well-funded opposition to the Cape Wind project. Wealthy coastal residents were surprised and outraged to learn that a private developer planned to construct an offshore energy facility in Nantucket Sound. Opponents raised funds and established the Alliance to Protect Nantucket Sound ("Alliance"), a 501(c)(3) environmental *non-profit* organization. By the Spring of 2002, the organization had launched its fund-raising and public relations strategy.

According to its webpage (available at http://www.saveoursound.org), the Alliance is dedicated to the long-term preservation of Nantucket Sound through "conservation, environmental action, and opposition to inappropriate industrial or commercial development." While not against wind power in general, the Alliance maintains that by placing the "industrial" facility in Nantucket Sound, Cape Wind threatens the coastal ecosystems of mainland Cape Cod and the Islands: Nantucket and Martha's Vineyard (Alliance to Protect Nantucket Sound 2009, 2014).

Initially, the Alliance emphasized the aesthetic and environmental risks of the project, including the "visual pollution" and the threats to protected wildlife, including birds that might be struck by wind turbines 440 feet above sea level. The Alliance's media campaign also claimed that Cape Wind threatened Nantucket Sounds' tourism industry and recreational areas.

Over time, as comprehensive impact studies determined that the environmental risks of Cape Wind were "negligible," the opposition has argued that:

- Public safety hazards include obstacles to marine vessel navigation, air traffic control, fishing vessel and gear deployment, and search and rescue efforts (Larson 2011).
- Cape Wind's electrical service platform will hold 40,000 gallons of transformer oil that, in the event of a rupture, would reach Cape and Islands beaches within 5 h.
- The "wealthy energy developer" has an arrangement that most can only dream about: "a no-bid, non-competitive deal for development rights on 24 square miles of Nantucket Sound for the largest industrial offshore wind energy complex in the world" (Roll Call 2006).

13.2.2 Other Stakeholders

Other stakeholders engaged in the conflict include the media, particularly the *Boston Globe* and *Cape Cod Times* initially, and at a national level, *The New York Times* (Burkett 2013). In addition, a wide range of public, private and independent stakeholders are involved.

Examples of other major stakeholders:

- Tourism and business organizations, such as the Cape Cod Chamber of Commerce;
- Recreational fishing and boating, such as Wianno Club and Osterville Anglers Club;
- Tribal nations, such as the Mashpee Wampanoag Tribal Council;
- Commercial fishing groups, such as the Cape Cod Marine Trades Association;
- Academic and scientific institutions, such as Woods Hole Research Center;
- Business, trade and labor organizations;
- Civic organizations, such as the Cape Cod Area League of Women Voters; and
- Environmental organizations, such as Clean Power Now, The Coalition for Buzzards Bay, and the Conservation Law Foundation.

Ultimately, federal, state and local energy and environment policies determine the fate of this offshore energy project. The first US offshore wind turbine facility gains legitimacy through legal compliance and federal, state and local permit approvals.

The US Federal Government has jurisdiction over resources from three to 200 nautical miles off US coastal shores, in an exclusive economic zone (EEZ). The Council on Environmental Quality, National Environmental Policy Act (NEPA), oversees the entire project. Review of the project began with the US Army Corps of Engineers ("Corps"), which took 3 years (2002–2004) to prepare a comprehensive Draft Environmental Impact Statement (EIS) as required by the National Environmental Policy Act (US Army Corps of Engineers 2014). In 2005, authority to approve offshore wind turbine projects was transferred to the Minerals Management Service (MMS) within the Department of the Interior. The MMS required its own environmental assessment, and after a comprehensive three-year study, issued a favourable Final EIS in January 2009. Other federal agencies with jurisdiction include:

- US Environmental Protection Agency (upland component and emissions)
- Federal Aviation Administration (navigable airspace)
- US Department of Energy (Energy Efficiency and Renewable Energy; Wind Program and the National Renewable Energy Laboratory)
- US Coast Guard (navigable waters)

Commonwealth of MA: Cape Wind must adequately and properly comply with the Massachusetts Environmental Policy Act (MEPA). Approval is required for the transmission lines to be placed in the three nautical miles of state waters, and the state may also require characterization of project alternatives; oceanographic modeling data of Nantucket Sound's sediment transport pathways and how they could be affected by the project; data on use of the Sound by birds and aquatic organisms; and analysis of the project's visual impacts (Provincetown Center for Coastal Studies 2003). Other state agencies with jurisdiction within three-mile state territorial seas limit include:

- MA Energy Facilities Siting Board and MA Coastal Zone Management
- MA State Historic preservation Officer and MA Historical Commission

Local Governments: The permitting boards of Barnstable, Yarmouth and the Cape Cod Commission have the authority to review plans and grant permission for Cape Wind to build transmission lines through their towns. The Massachusetts Electrical Facilities Siting Board has the authority to overrule local permitting boards. Other local agencies with jurisdiction within three-mile state territorial seas limit include:

- Yarmouth Conservation Commission and Yarmouth Department of Public Works
- Barnstable Conservation Commission and Barnstable Department of Public Works

Directly and indirectly, all local residents are stakeholders. As described below by John K. Bullard, (New Bedford Mayor 1986–1992), communities west of Cape Cod, along Buzzards Bay, which is the main shipping channel for tank barges that carry the fuel oil required for regional power plants, are particularly vulnerable.

> I live in New Bedford where we have always looked at smoke stacks, factories, outfalls, jails, railroads, hurricane barriers and all the other things that society needs. A year and a half ago we looked at 98,000 gallons of #6 oil wash up on our beaches because the incompetent barge operator couldn't find his way all the way to Canal Electric. We breathe polluted air from last generation power plants. Our young people give their lives in Iraq protecting a foreign source of oil. The good people in the Vineyard, Nantucket and the Cape who do not want their view "spoiled" benefit because so many of the "ugly necessities" get provided by people who are out of their sight. I have no sympathy. (Bullard 2004)

13.3 Analysis of the Conflict

How to analyze a protracted conflict that involves multiple stakeholders and is complicated by regulatory requirements, intense lobbying efforts and ongoing litigation? It is clear that, in contrast to bilateral or two-party negotiations, multiparty (multilateral) conflicts are complex and difficult to resolve. Factors that complicate environmental negotiations include:

- Multiple sectors, industries, organizations and institutions
- Multiple jurisdictions, regulations, policies and permits
- Incompatible values and interests
- Scientific uncertainty

Multilateral negotiation is understood as interactive communication that provides opportunities for interested stakeholders to engage in deliberations and decision making (Lang 1994). A flexible, adaptable approach includes public consultations, the discussions of procedural requirements, and bargaining over the substantive details of the case. Aggressive legal tactics and avoidance are examples of inflexible approaches (Larson 2003).

One way to study the complex multilateral dynamics is to identify the significant actions, events or ideas driving negotiations toward or away from an integrative resolution of the conflict.

Turning points are clear and self-evident changes from earlier patterns in the negotiations. The departures from earlier patterns are often surprising, and they may or may not be abrupt (Druckman and Olekalns 2011). Typically, turning points signal the movement toward or away from an integrative resolution of the conflict (Hall 2007). Actions that precede and are associated with turning points are sometimes called "triggers." The results, outcomes and effects of turning points in the negotiations are often classified as "consequences."

The priorities and resources of parties in negotiations can be categorized according to three interrelated dimensions of power: assets (material), legitimacy (social) and opinion (symbolic). These stakeholder priorities and resources are described in greater detail in Fig. 13.2, which describes and illustrates inter-related dimensions of power influencing the negotiations.

The Turning Point Matrix (Fig. 13.3) organizes stakeholder resources and priorities into a visual explanation of the negotiation of the Cape Wind project over time. The Turning Point Matrix (Fig. 13.3) shows:

- Dimensions of power: material assets, opinion and legitimacy
- The first phase of the four-phase negotiation
- Priorities of Cape Wind project supporters (top half)
- Priorities of project opponents (bottom half)
- Movement in support (+) or opposition (−) to the project (trend line)
- The "trigger" actions that precede and are directly associated with turning points (side box)
- Major turning point (Δ) in Phase I (bold italics)

- **Assets** are material resources such as property, capital and credit. Material assets can produce goods and services, and they can be controlled. Examples include private sector investments, loan guarantees and public sector tax credits.
- **Legitimacy** is acquired and exercised through governance structures, authority roles and well-founded rules. Examples include laws, regulations, permit procedures, legal rulings, and actions by legislative, executive and judicial authorities.
- **Opinion** is a psychological dimension of power. Beliefs, attitudes and reputation are shaped through narratives, dialogue, education, scientific information, personal experience and various forms of media marketing, particularly vivid images.

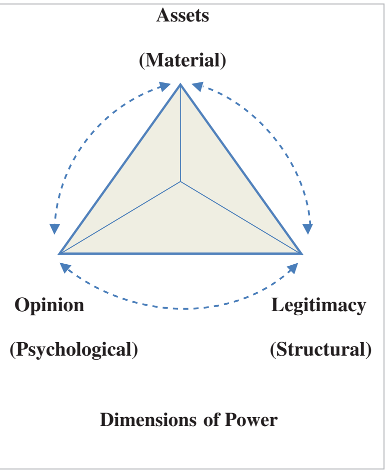

Fig. 13.2 Dimensions of power

PROJECT SUPPORT	Phase I	Phase II	Phase III	Phase IV
ASSETS	Initial Private Investments			
LEGITIMACY	Legal/Permit Requirements			
OPINION	Clean Energy EIS[1]*/Science			

[+]

2001 2003 2006 2010 2015

PROJECT OPPOSITION	Phase I	Phase II	Phase III	Phase IV
ASSETS	*Well-funded "Alliance"* Δ			
OPINION	PR/Media *Save Our Sound*			
LEGITIMACY	Legality? Lobbying			

[-]

EIS=Environmental Impact Statement PR=Public relations Δ Turning Points

Fig. 13.3 Cape wind project: turning point (Δ) matrix: phase I (2001–2002)

Cape Wind 'Triggers' and 'Turning Points' in Phase I of the conflict are described below.

Phase I, Trigger #1: In July 2001, as indicated in the side box of Fig. 13.2, a *Boston Globe* news report unveiled preliminary plans to develop America's first offshore wind farm in Nantucket Sound. Cape Wind developers proposed a substantive change to the

Cape Cod environment. The *Boston Globe* news article, "Offshore Wind Farm Blows Into Cape View," described Cape Wind as "landmark" project of "unprecedented scope" that could place Massachusetts at the forefront of wind power development. The article also recognized hurdles, including the "resistance from Cape Codders and islanders who don't want windmills marring their million-dollar ocean views" (Krasner 2001).

Phase I, Turning Point: News of the offshore wind turbine facility set in motion or triggered a focused, well-funded opposition to the perceived threats. In this first phase of the negotiations, wealthy individuals consolidated resources and formed a single-issue, professionally staffed organization: the Alliance to Protect Nantucket Sound ("Alliance"). Cape Wind executives did not expect and were not prepared for the Alliance's well-funded, unwavering, single-issue opposition.

Consequences: To date (July 2014), the Alliance's public relations, legal and political experts have achieved the organization's stated mission: to delay and/or block the construction of offshore wind turbines in Nantucket Sound. The Alliance, a not-for-profit organization, continues to raise tax deductible donations for the campaign to "save" Nantucket Sound.

The Alliance's first priority, with long-term benefits, was the branding or *framing* of Nantucket Sound as a "national treasure." With newspaper, radio and television commentary and advertisements, opponents described Cape Wind as an "industrial" threat to this "pristine" body of water. In the summer of 2002, the Alliance's media campaign featured Walter Cronkite, a broadcast journalist often cited as "the most trusted Man in America" (Zimmer 2009). Infomercials described Nantucket Sound as a "sanctuary" and included references to New England's marine heritage.

In addition, through aggressive legal action, the Alliance attempted to block the installation of the Cape Wind's data collection tower. Project opponents took their case to federal, state, county courts, and ultimately, to the US Supreme Court, where their petition was denied. These tactics delayed installation of the wind data tower by more than six months, kept Gordon in court—and cost Cape Wind an extra quarter million dollars in legal fees.

By characterizing Nantucket Sound as a sanctuary and raising environmental, safety and economic fears, the Alliance established negative opinions of the offshore wind energy project. At this stage of the multi-party negotiation process, environmental organizations such as the Conservation Law Foundation, Natural Resources Defense Council, the Sierra Club and others remained neutral as they awaited the results of the Corps' comprehensive environmental impact assessment. At this time, the Massachusetts Audubon Society was sceptical, which made their decision to support Cape Wind quite significant.

Cape Wind: In 2001–2002, Cape Wind's permit approval and other procedural requirements monopolized Cape Wind's time and resources. Regulators, investors, environmental organizations and other interest groups awaited the results of the US Army Corps of Engineers' scientific (evidence-based) assessments of the project's potential impact.

The Corps' Environmental Impact Statement (EIS) required public consultations and scientific assessments of (a) the need for and purpose of the Cape Wind project, (b) the suitability of alternative locations, and (c) the consequences of building and operating the project on Nantucket Sound. The assessors considered people (including tribal consultations), animals, plant life, soil, waterways, air quality, air travel, navigation, and other traffic. Potential impacts were to be categorized as *negligible*, *minor*, *moderate* or *major.*

Cape Wind executives did meet with politicians, civic, community and environmental associations and the media to build public support for this offshore wind energy project (Williams and Whitcomb 2007). As described below, they encountered various forms of avoidance and resistance. For example, Jim Gordon tried repeatedly to meet with Senator Edward Kennedy (D-MA), the senior politician from Massachusetts. However, the Senator and his staff refused Cape Wind's request for an appointment.

13.3.1 Phase 1, Negotiation Tactics

The timeline below describes significant negotiation behaviors during Phase I of the Cape Wind conflict (Cassidy 2010). This summary includes examples of flexible behaviors, such as willingness to discuss interests and differences, and inflexible (win/lose) behaviors, such as avoidance, exclusion, negative branding and litigation.

Fall of 2001: Jim Gordon tried to meet with Senator Ted Kennedy (D-MA) to discuss plans for the Cape Wind project. Senator Kennedy would not return his phone calls, and the Senator's staff were unwilling to meet.

November 2001: Cape Wind Associates LLC submitted its application to the US Army Corps of Engineers. The Corps took 3 years (2002–2004) to prepare the comprehensive draft Environmental Impact Statement (EIS).

December of 2001: Jim Gordon tried to arrange a public meeting with members of the Cape Cod Chamber of Commerce. This request for a public meeting was rejected. Instead, Gordon met with the Executive Committee. Following that meeting, on December 21, the Cape Cod Chamber of Commerce announced its opposition to Cape Wind.

January 2002: Barnstable Town Council voted to oppose Cape Wind. The town council's resolution claimed that the facility was "devastating" and would be visible 20 miles away.

April 2002: US Army Corps of Engineers, responding to political pressure, organized public hearings on the data-collection tower at the Barnstable Town Hall. During the hearings, local politicians raised concerns about the environmental impact of the Cape Wind facility. Following the hearings, the Corps consulted with other agencies. These were unusual additions to the Corps' routine permitting procedures. These procedural caused a 6-month delay in the permitting process.

June 2002: Cape Wind opponents held a fundraiser at the Wianno Club. Donors contributed approximately USD $4,000,000 to launch the Alliance's public relations and lobbying campaign. Doug Yearly, first President of the Alliance, assured donors that he would block Cape Wind, starting with the permits required for a wind data collection tower. Without evidence of the wind power output, Cape Wind would lack the data to raise capital in financial markets.

Summer of 2002: The Alliance hired Community Counseling Service (CCS), a public relations and marketing firm, to redefine and brand Nantucket Sound a "national marine sanctuary."

Summer of 2002: Senator Ted Kennedy proposed energy bill amendment that would require a National Academy of Sciences study before permitting any offshore energy facilities in the outer continental shelf.

August 1, 2002: Senator John Warner (R-VA), using US Senate stationary, wrote a letter to US Under Secretary of the Army, Les Brownlee to influence the Corps' permitting process. In a handwritten note, Warner described Nantucket Sound as a "national treasure."

August 16, 2002: Senator John Warner sent the Corps another letter. He described Nantucket Sound as a "fragile ecosystem" and threatened to take legal action to block permit approvals.

August 2002: US Army Corps of Engineers approved the permit for Cape Wind's data-collection meteorological tower to measure wind speeds and gather data.

August 2002: Opponents challenged the Corps' wind data permit approval in state and federal courts. A lawyer opposing the project charged that Cape Wind's data tower would gain "an unwarranted foothold in [a] pristine, environmentally protected area." Opponents also filed a challenge in the US federal court in Boston.

September 2002: The Alliance recruited Walter Cronkite and Robert F. Kennedy, Jr. to oppose Cape Wind through a media campaign.

September 2002: A Massachusetts state superior judge granted a 10-day restraining order to halt work on the tower. The federal court granted the Corps until Oct 27 to respond to claims that the Corps overstepped its authority when granting the permit to Cape Wind (Locke 2002).

October 2002: Opponents filed a challenge to the Corps' permit in Barnstable County.

November 2002: Federal judge ruled against opposition groups and allowed Cape Wind to erect a test wind tower in Nantucket Sound.

November 2002: Congressman William Delahunt proposed that Nantucket Sound qualify as a "national marine sanctuary," a federally protected area with special conservation, historical, cultural, archaeological, scientific, educational, ecological, or aesthetic qualities.

13.4 Lessons for Environmental Negotiations

> I would not speak about 'absolute' truths, event for believers…Truth is a relationship. As such, each one of us receives the truth and expresses it from within, that is to say, according to one's own circumstances, culture and situation in life.
>
> Pope Francis, Letter to Eugenio Scalfari. September 4, 2013

In Phase I, the true impact of the Cape Wind project was unknowable. Instead, through media narratives and other forms of storytelling, Cape Wind and the

Alliance defined and described Nantucket Sound and the wind farm in accordance with their own circumstances, interests and situations.

In 2001–2002, Cape Wind focused on the multiple benefits of clean, renewable wind energy. The company's reputation was not perceived at risk. Mark Rogers, Communication Director, explained: "EMI, coming into Cape Wind, had an excellent reputation with environmental, labor, and business organizations and regulators because of our history of building energy facilities that were efficient, safe, and clean with excellent operating histories."

The Alliance, though not opposed, in general, to diversification through clean renewable energy, *framed* public understandings of Cape Wind to heighten resistance and interfere with the procedures required for project permits and approvals. With the guidance of media and marketing experts, the Alliance conducted paid advertising and direct mail campaigns that emphasized the risks and threats of a greedy developer and an "industrial" facility in Nantucket Sound. The rallying cry: "*Save Our Sound!*"

Negative preconceptions posed serious challenges to the US Army Corps of Engineers when, in 2004, scientists finally presented the first draft Environmental Impact Statement (EIS) to the public. Many Cape Cod residents had already decided to oppose the Cape Wind project without considering the science-based assessment of its potential impact. Public opinions were influenced by compelling descriptions of the risks of Cape Wind to wildlife, livelihoods, and the scenic views and recreational activities associated with Nantucket Sound.

The tendency to confirm existing beliefs is called *confirmation bias*. People tend to prefer—and seek—information that confirms a pre-existing opinion. As noted by Mark Twain,[6] "Its easier to fool people than to convince them that they have been fooled". Research indicates that selective thinking is stronger when the issue generates emotions of fear of loss (Kahneman 2011). When convinced of a threatening situation, a fearful public will more readily accept inflexible negotiation behaviors, such as avoidance (shunning) or aggression. Legal action is generally framed as self-defense (safety, territory, etc.). Its "us" against "them".

13.5 Conclusion: First Mover Advantage

This paper has focused on the first 2 years of the Cape Wind conflict. In this first phase, opponents of Cape Wind effectively organized themselves and launched an aggressive public relations, legal and lobbying campaign. The early formation of the "Alliance" served as a turning point in the negotiation. Cape Wind opponents gained a first mover advantage by consolidating assets to influence public opinion, mobilize political support, and delay Cape Wind's permitting approvals.

At the center of the controversy is Nantucket Sound, an area of the Atlantic Ocean under federal jurisdiction. Multiple stakeholders have an interest in this body of water, including powerful coastal residents, civic and environmental

[6] Mark Twain is the pen name of US author Samuel Langhorne Clemens, (1835–1910).

organizations, commercial interests, and federal, state, and local jurisdictions. Through various forms of negotiation, including media communication, the Alliance characterized this marine ecosystem as a significant “national marine sanctuary.”

This analysis provides evidence that psychological factors, such as beliefs, values and intentions, are essential sources of power in environmental negotiations (Susskind 1994). The Alliance has not acknowledged the potential gains of Cape Wind, nor has the Alliance engaged in constructive deliberations about the merits, risks, size, location or other details of the renewable energy project. Instead, with funding from affluent coastal residents, the organization has moved quickly to raise public fears and generate the political support required to block the project.

From the start, the Alliance framed the threats of wind turbines as significant—and the benefits of clean, renewable energy technologies as invisible. For many local residents, including merchants, fishermen and summer vacationers, the fear of loss has been stronger than the willingness to learn more about the long-term benefits of offshore wind energy.

How does this analysis of early negotiations contribute to the resolution of water and environmental conflicts? The Cape Wind case demonstrates that public opinion matters (Carpenter and Kennedy 1991). The Alliance gained an early advantage in this complex, multi-party negotiation by focusing public attention on unsubstantiated risks to Nantucket Sound. The early definition of Cape Wind as an economic, social and environmental threat provided the rationale, and set the stage, for the inflexible, aggressive negotiation strategy that followed.

Reputation has been Cape Wind’s vital strength—and risk—in the negotiation of this complex environmental conflict. Gradually, following more than 6 years of federal environmental impact assessments, Cape Wind has been able to provide science-based evidence that the offshore renewable wind energy will meet the needs of present generations without compromising public safety or the ability of future generations to meet their own needs. Cape Wind’s consistent, explicit focus on legitimacy, sustainability and corporate responsibility has made it possible to realign public opinion and justify political support for the project.

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Part IV
Ecological and Socio-Economic Impacts

Chapter 14
Quantitative Evaluation of Hydromorphological Changes in Navigable Waterways as Contribution to Sustainable Management

Nathalie Cron, Ina Quick and Stefan Vollmer

Abstract A quantitative evaluation method called Valmorph (eVALuation of MORPHology) was developed by the German Federal Institute of Hydrology (BfG). It was used to identify hydromorphological changes based on representative hydromorphological indicator-parameters. Information on reference conditions representing the basis for any hydromorphological assessment was derived from historical data analysis. By comparing recent and historical data, an evaluation is possible, in which historical data are assumed to represent natural or near-natural conditions. Outputs of this procedure are critical river sections in terms of hydromorphological attributes. BfG evaluated changes in hydromorphological characteristics for the German part of the inland Elbe River (from the Czech border to the tidal weir at Geesthacht—586 km). This work was done on the request of the Elbe River Basin Association and contributes to the Sediment Management Plan for the Elbe River. For the Elbe River an example is presented using the parameter "structure of the riparian zone", which is of particular interest because it has a natural function as a source and sink for sediments. Changes in the riparian zone (e.g., bank fixation and groyne fields) have a large effect on river morphology and could also have considerable effects on habitat development and distribution. The evaluation results were summarized in their entirety for the six investigated hydromorphological parameters used as indicators for river sections in a poor hydromorphological condition. This serves as a basis for making well-reasoned decisions on measures and management options to improve hydromorphological characteristics and support the prioritisation of measures in decision-making processes.

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_14

Keywords Morphology · Federal waterways · Elbe River · Structure of the riparian zone · Sediment management

14.1 Introduction

The European Water Framework Directive (EC-WFD) (European Water Framework Directive 2000) is the key initiative and legal basis aimed at improving water quality throughout the EU (Koenig et al. 2012; Benjankar et al. 2013). The strategic objective of the European policy on waters—a good chemical status (gcs) as well as a good ecological status (ges) of natural surface- and ground-water bodies until 2015 or a good ecological potential (gep) for heavily modified and artificial surface-water bodies—is pursued by an integrated river-basin management (Raven et al. 2002; Weiss et al. 2008; Vollmer et al. 2012).

The EC-WFD demands an integrative and international consideration of river basins and is implemented in national legislation. Surveys, assessment, and management are tasks which have to be processed by the national river basin associations (Vollmer et al. 2012).

In the EC-WFD, the hydromorphological parameters are only used to support biological quality components (Raven et al. 2002; Weiss et al. 2008). But it is nevertheless essential to keep in mind that they are of decisive importance for the condition and characteristic of habitats and thus for the achievement of the targets pursuant to EC-WFD (European Water Framework Directive 2000; Linnenweber 2011; Naumann 2011; Törkel 2008).

In the last few centuries, hydromorphological conditions of streams were altered due to anthropogenic measures pertaining to navigability, flood protection, hydropower, land use and so on. Typical structural modifications are river bed and bank fixation, straightening, deepening of the navigation channel, disturbance of the river continuity (e.g., barrages that induce backwater areas) (Benjankar et al. 2013).

Such measures contribute to degraded river systems in terms of hydromorphological heterogeneity and consequently to a loss in habitat diversity (Gostner 2012). As can be seen in Fig. 14.1, barrages can lead to a loss of near natural structures, changes in the grain size distribution (structure and substrate of the river bed) and interrupt the sediment transport of the river bed (river continuity). Furthermore, barrages induce a discontinuity of longitudinal migration which may lead to fragmentation of the aquatic fauna and to genetic isolation.

Hence, the evaluation of natural changes and anthropogenic influences is essential. Knowledge of reference conditions regarding sediment budget and hydromorphological conditions and processes is therefore necessary (Raven et al. 2002), because sediments and hydromorphological parameters are closely linked. Sediments are relevant for the characteristics of hydromorphology, and vice versa: the hydromorphological elements also influence the sediment budget and the sediment transport processes like sedimentation and erosion. Hydrological conditions as well as morphological characteristics and processes provide a variety of habitats in

Fig. 14.1 Development of the river Mosel at Lehmen (near the city of Koblenz) from 1957 to 2006 (*source* Waterway and Shipping Office Koblenz). The *black circles* show the development of the isle “Reiherschuss” due to the construction of the barrage

river ecosystems. Alterations of the hydromorphological conditions of a water body can affect the ecological functioning of the system (Quick 2012) (e.g., changes in sediment composition can affect the habitat diversity for biota).

Due to missing reference locations for natural or near-natural conditions, it is difficult to produce a quantitative description of indicators characterizing the hydromorphological reference conditions and processes. However, the use of historic data provides good opportunities to investigate and evaluate the impacts on the hydromorphology due to anthropogenic influences and improve understanding of the system.

The German Federal Institute of Hydrology developed the so-called module Valmorph (eVALuation of MORPHology), which is a module for the detection and evaluation of changes of the hydromorphology of rivers and their floodplains, to quantify hydromorphological indicators. To analyse these representative hydromorphological parameters, historical data were compared with current data, resulting in an evaluation (Koenig et al. 2012; Rosenzweig et al. 2012; Quick et al. 2012). Hereinafter, the methodology is explained using the parameter "structure of the riparian zone", which shows strong interrelation with the river morphology as well as habitat development and distribution (Wieprecht 2010; Fleischer and Schilling 2011; Brunke 2008; Groll and Opp 2008). This parameter is one out of several parameters which were developed for Valmorph (Rosenzweig et al. 2012) (see Sect. 14.3). Furthermore, an example pertaining to the German inland Elbe River is given.

The Valmorph method was developed on behalf of the German Federal Ministry for Transport, Building and Urban Development (BMVBS) and enables a quantitative survey of hydromorphological parameters. This permits a documentation and evaluation of the development of the river morphology and the hydromorphological and sedimentological conditions. Comparing the Valmorph method to other assessment methods applied in Germany (e.g., the LAWA overview (LAWA 1999) or the LAWA on-site survey (LAWA 2001), which were developed by the LAWA, a German Working Group on water issues of the Federal States and the Federal Government represented by the Federal Environment), it can be seen that the degree of detail is much higher using the Valmorph method (see Sect. 14.4). The Valmorph method provides an integral role for subsequent considerations of ecological aspects and also serves as a basis for sediment management. It provides sedimentological and hydromorphological results for the planning, realisation and efficiency control of measures and serves as a detection and evaluation framework for supporting the assignments and requirements of federal waterways in Germany. This quantitative approach is the opposite of the hitherto existing verbal and qualitative analysis of river morphology (Rosenzweig et al. 2012).

14.2 Example of a Hydromorphological Assessment: "Structure of the Riparian Zone"

Valmorph was first created to enable the assessment of hydromorphological conditions in quantitative terms, e.g. for the subsequent use in environmental impact studies. Valmorph is part of the INtegrated FlOodplain Response Model

(INFORM) developed by the German Federal Institute of Hydrology (BCE & ConTerra GmbH 2010; BfG 2011). The modelling framework of INFORM considers significant interactions between hydrology, morphology and riverine organisms (e.g. plant habitats) in the river ecosystem, comprising the river stretch, river banks and the floodplain. It combines conventional hydro-numeric models with ecological modelling techniques to predict and evaluate ecological impacts of river engineering projects (Fuchs et al. 2012). The hydromorphological components of the module Valmorph lead to a consideration of morphodynamic and hydromorphological aspects in INFORM.

Regarding the hydromorphological indicators (that were chosen predominantly in conformity with the hydromorphological quality components named in the EC-WFD), an assessment was chosen using five evaluation classes, namely high, good, moderate, poor and bad hydromorphological conditions. Such a grading is consistent with the EC-WFD approach (Raven et al. 2002; Vollmer et al. 2012; Rosenzweig et al. 2012; DIN 2005; DIN 2010).

Threshold values separating the individual classes were fixed by expert judgement along with existing national and international scientific standards, e.g. DIN 14614 (2005) and 15843 (Weiss et al. 2008; DIN 2010; CIS-ECOSTAT 2006). Class 1 (high) corresponds to natural or near-natural conditions. Anthropogenically conditioned deviations from the reference were used as a measure for the definition of the subsequent classes (Raven et al. 2002; Vollmer et al. 2012; Rosenzweig et al. 2012; Quick et al. 2012; DIN 2005, 2010). In the following paragraphs, the methodology for the example "structure of the riparian zone" is described in general.

The riparian zone is limited by the top of the bank, whereas the lower limit of the riparian zone is represented by the mean water level (Rosenzweig et al. 2012; DIN 2005, 2010).

The parameter "structure of the riparian zone" is used as an indicator for the structural condition of river banks and river dynamics. Furthermore the riparian zone is a potential source and sink for sediments, which is important to consider when focusing on the diversity of habitats. Vegetation structures are part of the considerations of the parameter "structure of the riparian zone" due to its importance to habitat creation at the banks.

To evaluate this parameter, the length of existing natural bank structures will be investigated and evaluated. This is done by measuring the existing natural riparian zone of a survey section in metres. Subsequently, the percentage distribution will be calculated to permit a better comparison between the survey sections. The different types of anthropogenic bank fixations are not part of the evaluation.

The typical historical condition of the riparian zone is defined by the natural type-specific ensemble of relief features without anthropogenic influences. Consequently, it is assumed that the percentage of existing natural bank structures in the historical condition equals 100 % for the whole river stretch (of the inland Elbe) (Rosenzweig et al. 2012).

Concerning recent conditions, information can be gathered from remote sensing data (e.g. analysis of aerial images), different types of maps (e.g. digital map of the German federal waterways, scale 1:2.000) and in exceptional cases by field inspection (e.g. during environmental impact studies). Information about the vegetation structures can be obtained from Colour-Infrared aerial pictures or biotope mapping. The recent condition of the riparian zone will be detected as the so-called remaining natural riparian zone including unspoilt and unmodulated bank structures as well as sections with fixations that have largely been destroyed such that near-natural bank structures have become the dominating feature again. All sections with bank fixations (e.g. rock fill/riprap, groyne fields or artificially moulded bank structures) are mapped as modified bank structures (Rosenzweig et al. 2012).

To evaluate the recent condition, the remaining part of the natural riparian zone has to be measured for each survey section and has to be declared as a percent value (Rosenzweig et al. 2012). If the "structure of the riparian zone" corresponds to the historical condition, the parameter in this section will be evaluated as "1", because more than 90 % of the natural riparian zone is given. The percentage distribution from the recent to the historical condition is the measure for the evaluation. The assessment has to be conducted in the flow direction separately for the left and right river banks, and the assessment table (Table 14.1) has to be applied to each section (Rosenzweig et al. 2012).

To consider all the particularities of a river stretch, certain criteria can be used to upgrade the evaluation results (Rosenzweig et al. 2012). Therefore, bonus points are added, but it has to be considered that sections that are completely covered with bank fixations can only get a maximum classification of "3 (moderate)". Bonus points have to be added separately for each bank side.

Criteria for bonus points are:

- Sedimentation in groyne fields—If within the sections, 30–60 % of the bank fixations are covered with sediments, one bonus point is added. If there is more than 60 % covered, two bonus points are added (BfG 2001).
- Groyne field with natural bank line—Concerning bank fixation via groyne fields, one must distinguish between groyne fields with natural banks and those without natural banks. If there are natural banks between the groyne fields in at least 30 % of the evaluated section, one bonus point is added.
- Typical vegetation structure—If typical or natural vegetation structures (e.g. alluvial forest) can be detected in at least 30 % of the evaluated section, one bonus point is added.

Table 14.1 Assessment table for the parameter "structure of the riparian zone" for natural water bodies (Rosenzweig et al. 2012)

% natural "structure of the riparian zone"	Left/right "structure of the riparian zone"
>90	1
60–90	2
30–60	3
10–30	4
0–10	5

Bonus points for sedimentation in groyne fields are added, because the sedimentation can reduce the impact of groynes and re-establish a natural riparian zone. Although groyne fields with natural bank lines were taken into account, due to the reason that a natural bank line in between the groynes should be considered in a better way, concerning the evaluation, than completely fixed bank structures, natural bank lines in between groynes still enable a natural development of the riparian zone (even if it is only in a reduced way) especially during flood events. Concerning the typical vegetation structure, bonus points were implemented due to the positive effect of vegetation structures with regard to the sedimentation and erosion of sediments during higher discharges and flood events (contributing to channel and profile development). Furthermore, natural vegetation structures contribute to ecological diversity.

14.3 Case Study of the Inland Elbe River

The Elbe River originates in the Czech Giant Mountains and flows through the central and northern parts of Germany before discharging into the North Sea. It is one of the major waterways in Germany with a total length of 1,094 km and a river basin of 148.268 km^2. The upper reaches of the Elbe River in the Czech Republic are regulated by a series of barrages and reservoirs, whereas the river is free flowing from Usti-nad-Labem near the Czech-German border till the tidal weir at Geesthacht near Hamburg. The mean discharge is 862 m^3/s. This investigation is focused on the German part of the Elbe River to the tidal limit at the weir at Geesthacht (Fig. 14.2) from Elbe-km 0 until Elbe-km 586 (Koenig et al. 2012). Concerning the objective of the EC-WFD (European Water Framework Directive 2000), the German part of the inland Elbe River was designated as a natural water body.

The integral view on sediment management strategies is one of the fundamentals of the Sediment Management plan for the Elbe River on behalf of the River Basin Association Elbe (2013) and the International Commission for the Protection of the Elbe River (ICPER) ad hoc expert group “sediment management” (Vollmer et al. 2012; IKSE 2014). This view requires a detailed analysis of the Elbe system as a whole.

In the framework of the development of a Sediment Management Plan for the Elbe River on behalf of the SSeM Elbe (expert group on contaminants and sediment management of the River Basin Association Elbe) the following six hydromorphological indicator-parameters were investigated and evaluated for the German part of the inland Elbe River, using the module Valmorph (Elbe 2013; IKSE 2014):

- river depth and width variation;
- river depth variation—frequency and magnitude of the spatial change in water depth;
- river width variation—ratio between the largest and smallest width of the river bed

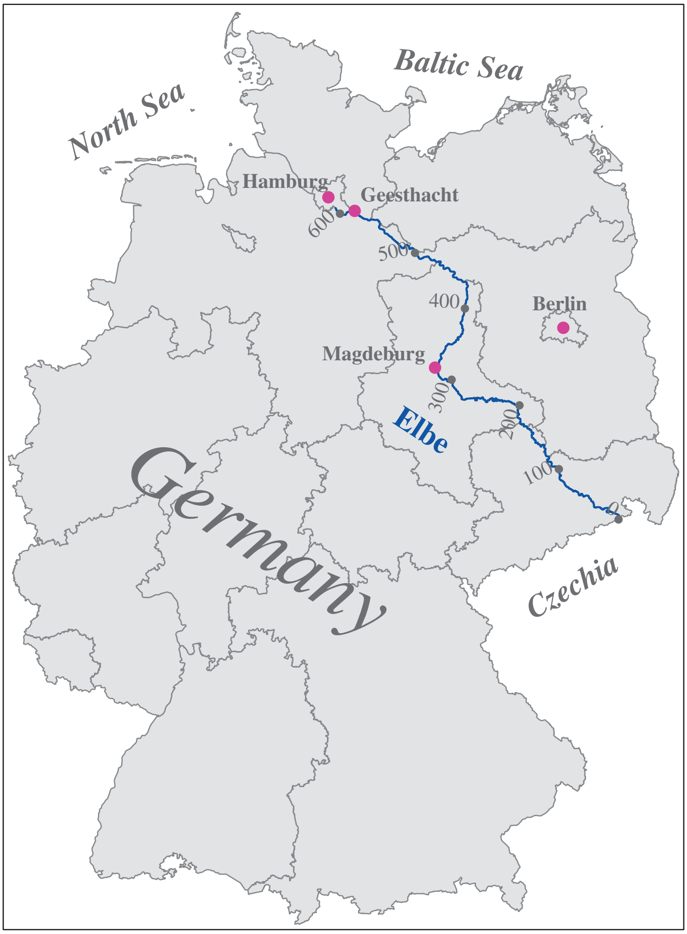

Fig. 14.2 Location of the German part of the inland Elbe River (Koenig et al. 2012) ©GeoBasis-DE/BKG (2014)

- river continuity for sediments;
- influences on sediment transport due to barrages
- mean grain size diameter (substrate of the river bed);
- analysis of modifications in the grain size distribution
- average bed level change/sediment balance;
- elevation changes of the river bed over time
- structure of the riparian zone;
- indicator for the structural condition of river banks and river dynamics
- ratio of morphological and recent floodplain areas;
- surface ratio between the original/natural floodplain area and the existing floodplain area

The analysis of these parameters improves the understanding of the hydromorphology of the Elbe River and quantifies changes due to river regulation and river management. The investigations and results allow an improvement of the hydromorphological conditions of the Elbe River (Elbe 2013; IKSE 2014). For an evaluation of these changes, current characteristics of the parameters are correlated with historical data, which serve as reference conditions (Rosenzweig et al. 2012; Quick et al. 2012; Elbe 2013; IKSE 2014).

The application of the methodology for the parameter “structure of the riparian zone” was conducted, as explained in Sect. 14.2, using the digital map of the German federal waterways (scale 1:2.000), which contains drawings of different fixation types, and additional aerial pictures were used (Fig. 14.3).

For the purpose of evaluation, information on the parameters was gathered for each kilometre section and the percentage distribution of the natural riparian zone was calculated. After the assessment of each kilometre section, bonus points were added. The evaluation results were finally averaged for river stretches with a length of 5 km (by using the average of the assessment classes).

Figure 14.4 shows the evaluation results for the parameter “structure of the riparian zone” for the left and right river banks on the whole part of the inland waterway Elbe.

Figure 14.5 depicts the percentage distribution of the different classes for each river side.

The results show that 6 % of the left riparian zone and 5 % of the right riparian zone are evaluated as “high” and “good”. Assessment of “moderate” ranges from

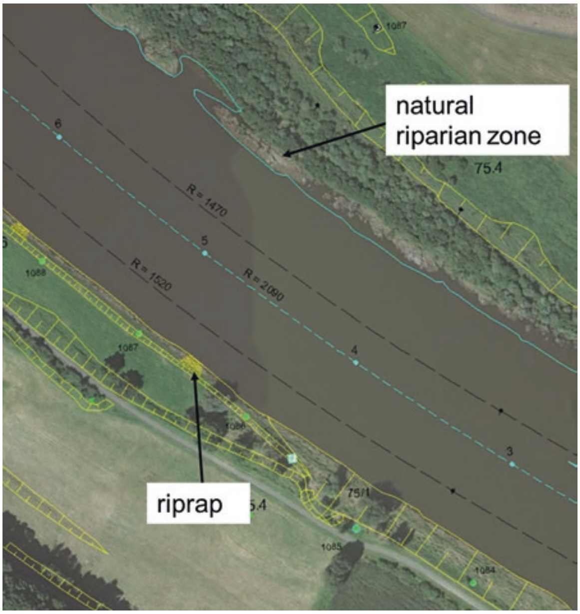

Fig. 14.3 Example of the used database (map of the German federal waterways—*coloured lines* and aerial picture; *source* Federal Waterways and Shipping Administration) ©GeoBasis-DE/BKG (2014)

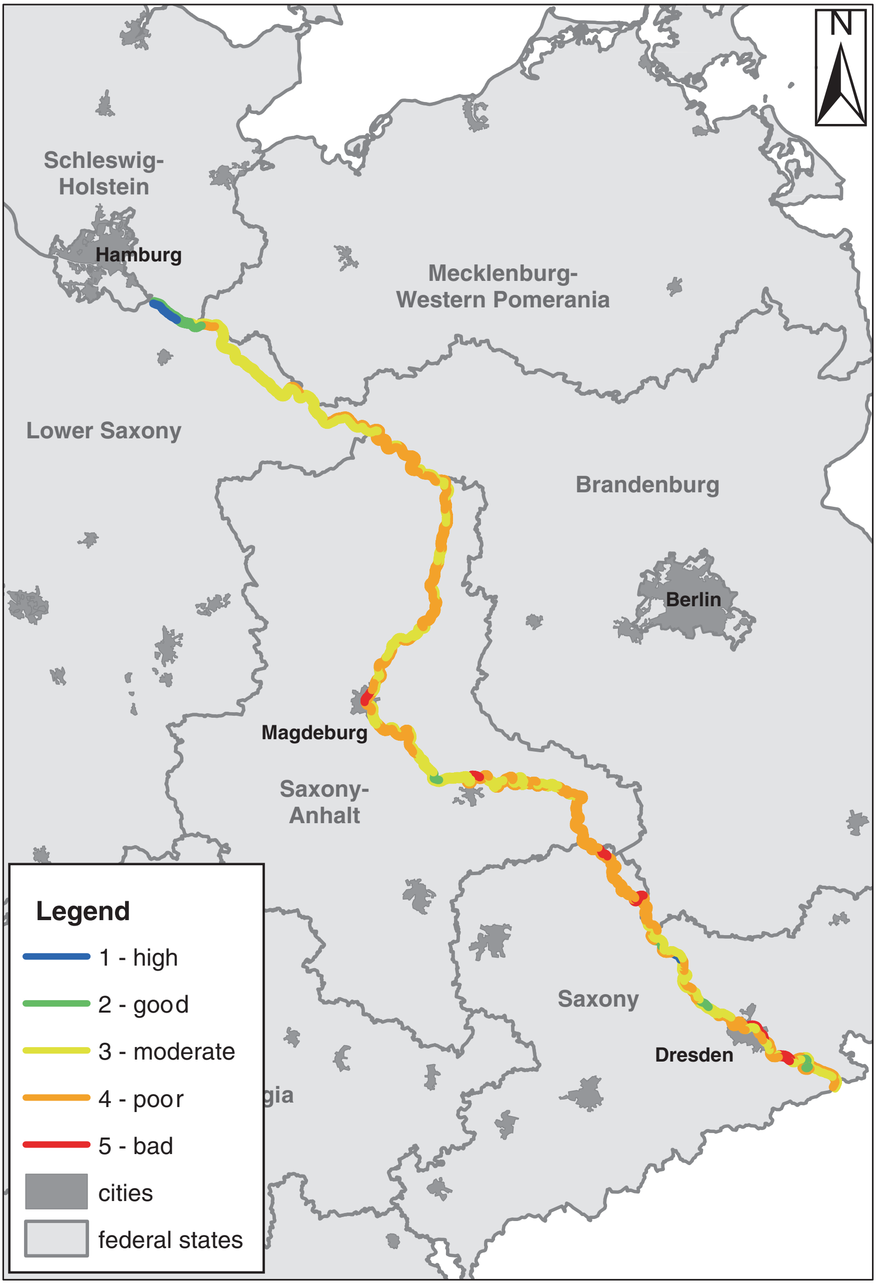

Fig. 14.4 Evaluation results for the parameter "structure of the riparian zone" for the inland Elbe River divided for the *left* and *right* river banks (Rosenzweig et al. 2012; Elbe 2013; IKSE 2014) ©GeoBasis-DE/BKG (2014)

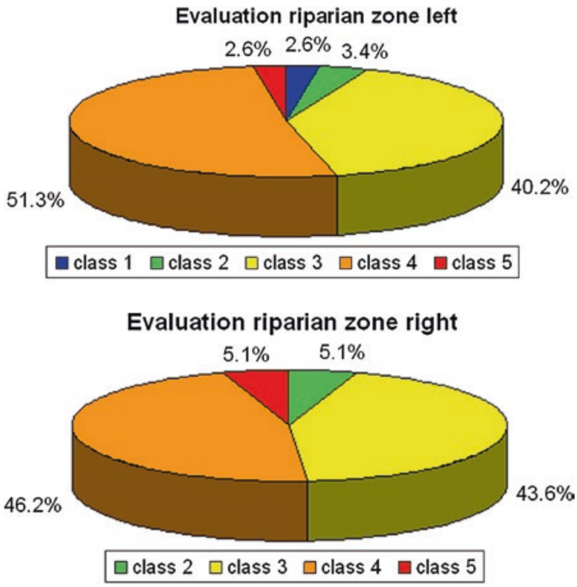

Fig. 14.5 Percentage distribution of the evaluation classes for the parameter “structure of the riparian zone” (divided) for the *left* and the *right* river stretch (*database* Elbe 2013; IKSE 2014)

40 % for the left riparian zone and 44 % for the right riparian zone. “Poor” evaluation shows the highest percentage distribution with 51 % for the left riparian zone and 46 % for the right riparian zone. “Bad” evaluation results are attained for 3 % of the river stretch on the left riparian zone and 5 % for the right riparian zone.

Both “high” and “good” classes indicate positive hydromorphological and sedimentological conditions, whereas all the classes ranging from “moderate” to “poor” indicate a need for improvement measures (Elbe 2013; IKSE 2014).

As can be seen in Figs. 14.4 and 14.5, the Elbe River shows a high degree of bank fixation. This leads to a decrease in river dynamics and also reduces the lateral erosion ability of the river in the riparian zone. Therefore, the existing banks can only contribute in a reduced way to sediment exchange. Other factors impart a negative influence on the sediment regime, e.g. reduced sediment continuity in the catchment area and the upper part of the Elbe River in the Czech Republic, river training that leads to a higher bottom shear stress in the river bed. To compensate this missing material and the negative sediment regime, the river takes sediments from its own river bed, leading to an increased degradation (see Elbe 2013; IKSE 2014). All these factors lead to a loss of habitats and reduce their availability and diversity. This consequently contributes to a decrease in species diversity (Wieprecht 2010; Fleischer and Schilling 2011; Brunke 2008; Groll and Opp 2008). It has to be taken into account that, although this is only one out of the six parameters, it already contributes to sediment deficit and influences the erosion ability of the river, which are the characteristics of concern.

Possible measures are the removal of bank fixations at sections, on the condition that river navigability is not affected in a negative way. Also, the use of near natural/alternative bank fixations can be an alternative measure. A joint research project between the BfG and the Federal Waterways Engineering and Research Institute (BAW) focuses on this subject and is currently being processed at the Rivers Rhine and Weser (Törkel 2008; Fleischer and Schilling 2011; Fleischer and Liebenstein 2008). Furthermore, the construction of different groyne types is possible, as well as establishing training walls instead of groyne fields. The construction of different groyne types and their ecological effect is also currently being investigated in a joint research project of BfG and BAW (Törkel 2008; Anlauf and Hentschel 2008). In another joint project between the BfG, BAW and the Waterway and Shipping office Eberswalde, a monitoring program was developed for the River Oder to investigate the hydromorphological and ecological development of a river section using a training wall instead of the reconstruction of groyne fields (Cron and Sundermeier 2012).

The methods used to evaluate each specific hydromorphological parameter are documented in Rosenzweig et al. (2012), FGG Elbe (2013) and IKSE (2014). The evaluation results can be shown together in a map using a 5 band diagram. This allows the detection of critical river sections, and possible improvement measures can be recommended. In Fig. 14.6 the results of four parameters are shown. The parameters are (from the left to the right):

- ratio of morphological and recent floodplain areas (left)
- changes in mean particle sizes (substrate of the river bed)
- average bed level change
- river depth variation
- ratio of morphological and recent floodplain areas (right)

To obtain a brief overview of the distribution of the evaluation results, the assessment of all investigated hydromorphological parameters (river depth and width variation, river continuity for sediments, mean grain size diameter (substrate of the river bed), average bed level change/sediment balance, “structure of the riparian zone” and ratio of morphological and recent floodplain areas) was calculated.

Therefore, the individual results of each evaluated parameter were used for the whole inland waterway Elbe. The results are shown in Fig. 14.7. The analysis of the percentage distribution of the evaluation classes shows that 64 % of the Elbe River are evaluated from “moderate” to “poor”, while 36 % of the hydromorphological parameters reach “high” and “good” conditions/evaluation results. The most important criteria, the river continuity for sediments and the average bed level change—sediment balance, were identified (Elbe 2013; IKSE 2014).

When deriving sustainable measures for sediment management, which can also contribute to environmental improvement, the evaluation results for each parameter are taken into account and are also compared to the results of the other parameters as can be seen in Fig. 14.6. Key regions of concern can be detected in this manner. In regions where a large number of parameters are evaluated as “poor”, a lot of measures have to be implemented to obtain better hydromorphological conditions. If a lot of parameters in a region are evaluated as “moderate”, on the other hand, improvement of hydromorphological characteristics requires less effort.

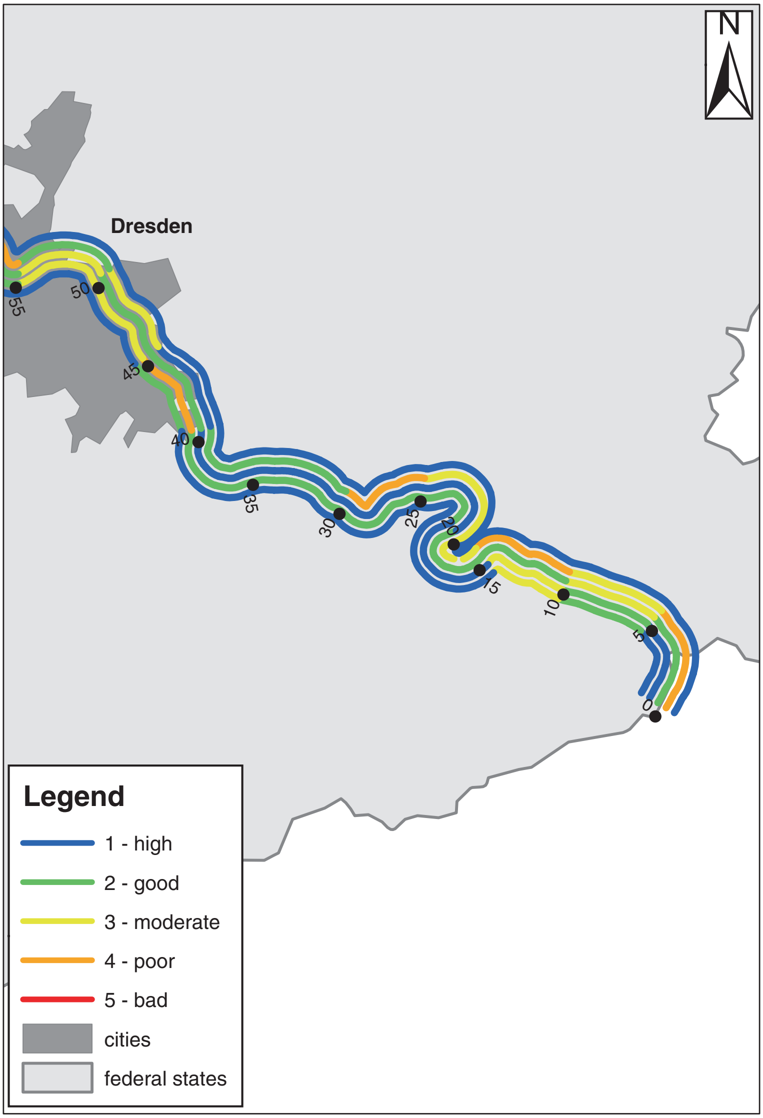

Fig. 14.6 Evaluation results of four chosen parameters (from the *left* to the *right*: ratio of morphological and recent floodplain areas—*left*; changes in mean particle sizes (substrate of the river bed), average bed level change, river depth variation, ratio of morphological and recent floodplain areas—*right*) for the first 50 km stretch of the inland waterway Elbe (Rosenzweig et al. 2012; Elbe 2013) ©GeoBasis-DE/BKG (2014)

The overall results of the evaluation provide an overview of the anthropogenic modified river sections, which can be attributed to, for example, the influence of barrages in the tributaries of the Elbe and in the Czech Republic, the construction

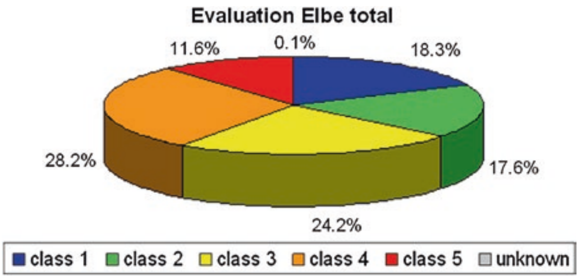

Fig. 14.7 Percentage distribution of the evaluation classes comprising all parameters (river depth and width variation, river continuity for sediments, mean grain size diameter (substrate of the river bed), average bed level change/sediment balance, structure of the riparian zone and ratio of morphological and recent floodplain area) for the whole river stretch of the inland waterway Elbe (*database* Elbe 2013; IKSE 2014)

of dikes and the reduction of floodplains, the homogenisation of river depth and width variation and, above all, the erosion of the river bed (Elbe 2013; IKSE 2014). All modifications together contribute to the loss of habitat structures for aquatic and terrestric organisms.

Subsequently, options of measures can be derived for a sustainable management of the water system. These measures are, for example, floodplain enlargements, reduction of barrages or the discontinuity for sediments, reduction of erosion (e.g. due to an optimised sediment supply strategy), reductions of bank fixations, or the use of near natural/alternative bank fixations. These measures contribute to many objectives, including the following: limiting depth erosion, reduction of bottom shear stress and promotion of a balanced sediment budget. They can additionally increase the availability of habitat structures.

14.4 Discussion

Comparing the Valmorph method to other assessment methods applied in Germany, e.g. the LAWA overview (LAWA 1999) or the LAWA on-site survey (LAWA 2001) (see Sect. 14.1), it can be seen that the degree of detail is much higher using the Valmorph method. The LAWA on-site survey was developed for small and medium size rivers and provides information for river restoration projects, whereas the LAWA overview survey serves as decision support and the implementation of the European Water Framework Directive (European Water Framework Directive 2000; Benjankar et al. 2013). Contrary to the LAWA overview (LAWA 1999) or even the LAWA on-site survey (LAWA 2001), the quantitative approach of the Valmorph method reveals more detailed information which is essential for a closer view on sediment and habitat dynamics. This serves as a basis for subsequent decisions on target-oriented adoption of possible measures (Wieprecht 2010).

The presented method Valmorph was first applied to the whole inland River Elbe. During the development of the method, several sections from other river systems, e.g. the River Rhein and Mosel, were evaluated. Application of the method to other river systems is planned. It has to be taken into account that a requirement for the application of this method is a good historical database. Therefore, the method was especially developed for navigable waterways, because they provide good historical data and information. Consequently, application of this method to smaller rivers will be difficult or almost impossible, depending on existing historical data (Rosenzweig et al. 2012; Elbe 2013; IKSE 2014).

This method should be applicable to the international context, although some parameters and evaluation tables may have to be adapted to regional and local type-specific conditions using available data or expert judgment.

The bonus-system especially supports near-natural structures at large and navigable rivers. This is an appropriate point at which to register and assess the beginning of a near-natural development of hydromorphological components.

With regard to the parameter "structure of the riparian zone", it must be emphasised that the assessment concerning the use of bonus points may lack a certain amount of validity if the discharges are different. Accordingly, there is some improvement potential, e.g. by using only low or medium discharges for every data source for each survey section. To increase the level objectivity of the method, it is suggested to take the measurement of all sections characterised by a high sedimentation and by natural banks in between the groynes. This is the input for a calculation of the percentage distribution of the remaining riparian zone with natural structures. Uncertainty remains about the kind of vegetation structures taken from aerial pictures. To get appropriate information about the vegetation structure, especially in wintertime, an assessment should be carried out by a botanist.

It must be taken into account that the evaluation results of all parameters (see Sect. 14.3 and Fig. 14.7) were only considered together, to give an overall view of the investigation. Measures are only derived concerning the individual results of each parameter and by comparing several parameters to each other. Therefore, detailed evaluation results should be obtained and used for further steps like improvement suggestions. Key regions of concern can be detected in this manner. In recommending variable measures, the different and often contradictory concerns of shipping and nature conservation have to be respected. Solutions should respect all interests.

Furthermore, these analyses can be used to identify existing deficits in the data base and subsequently enable an investigation on missing information.

14.5 Summary

Rivers are hydromorphologically altered due to anthropogenic impacts. To investigate and evaluate these hydromorpholgical changes, the Valmorph (eVALuation of MORPHology) method was developed by the German Federal Institute

of Hydrology (BfG), especially with regard to federal waterways. The method considers the requirements set by the European Water Framework Directive (EC-WFD) (European Water Framework Directive 2000). Valmorph, developed on behalf of the German Federal Ministry for Transport, Building and Urban Development (BMVBS), can be used to support various projects, such as contributing to sediment management, quantifying morphological changes, serving especially as a basis for biological elements and improving ecosystem understanding (see Sect. 14.2).

The evolved method was used in the framework of the development of the Sediment Management Plan of the inland Elbe River in Germany of the River Basin Association Elbe and the ICPER.

Through the investigation an improved understanding of the hydromorphology was attained and the extent of hydromorphological changes was quantified. The following six parameters from Valmorph are used for the purpose of the Elbe case study: river depth and width variation, river continuity for sediments, changes of mean grain size diameter (substrate of the river bed), average bed level change/ sediment balance, structure of the riparian zone and ratio of morphological and recent floodplain areas.

The methodology and the evaluation results are presented in detail for the parameter "structure of the riparian zone" by applying a comparison between current and historical data. Results for the remaining parameters are presented based on an aggregated hydromorphological assessment and are documented in Rosenzweig et al. (2012), FGG Elbe (2013) and IKSE (2014). The results clearly show hydromorphological changes of the river, and ecological impacts can be derived in a second step. The hydromorphological aspects are an essential basis for further biological examinations. An especially important finding is that the high degree of bank fixation—made visible by the results for the parameter "structure of the riparian zone"—contributes to a degradation of the river channel, in combination with other factors, such as the negative sediment regime, the missing continuity for sediments, the construction of dikes and the loss of floodplains (see Elbe 2013; IKSE 2014). For instance, the restrained interaction between the river, its riparian zone and the floodplain induces a loss of sediment material which leads to further erosion of the river bed. Furthermore, the results provide a quantitative measure of the magnitude and exposure for focus areas. In this way, improvement measures can be recommended to support a sustainable development of the water stretches.

Acknowledgments The authors would like to thank their colleagues Soenke Schriever, Dr. Frauke Koenig, Christian Svenson, Doreen Graetz and Klaudia Kroetz for their work in this investigation. We would also like to express special thanks to the ad hoc expert group SSeM of the River Basin Community Elbe (especially to Dr. Peter Heininger, Federal Institute of Hydrology, Koblenz) and to the expert group on sediment management of the ICPER (especially to Prof. Dr. Jakub Langhammer, Charles University, Prague). Particular thanks go to the River Basin Association (FGG) Elbe and the ICPER.

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Chapter 15
Agricultural Water Resources Limitations and Their Effects on the Socioeconomic Conditions of Wheat Farmers: A Case Study of Maku City in Iran

Parisa Salimzadeh and Khalil Kalantari

Abstract The agricultural sector of Maku city in West Azerbaijan province of Iran heavily depends on the natural potential and capacities of water resources. The main purpose of this paper is to study water resources limitations and their effect on the socioeconomic status of wheat farmers in the studied area. In this survey, required data have been collected via a questionnaire from 150 wheat farmers. The validity of the questionnaire was confirmed through Cronbach Alpha ($\alpha > 0.82$) and the data was analyzed using the factor analysis technique by SPSS software. Based on the results of this study, the limitations of water resources are summarized into four factors: atmospheric and natural conditions (23.33 %), pattern of water resources utilization (17.85 %), challenges of water resources management (14.74 %) and pattern of land utilization (11.88 %). Altogether, these four factors account for 67.53 % of the total variance of water resources limitations in Maku city. The effects of water resources limitations on the socioeconomic status of wheat farmers in this city are also summarized into three factors: economic effects (31.13 %), social effects (22.19 %) and environmental effects (14.89 %), accounting for 68.20 % of the total variance of the effects of water resources limitations on the conditions of the studied local wheat farmers.

Keywords Agricultural sector · Water resources · Land utilization · Socioeconomic status · Wheat farmers · Maku · Iran

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_15

15.1 Introduction

The annual average precipitation of Iran is less than one third of the world's annual average precipitation (Mahmodi 2003). Also, the temporal and spatial distribution of precipitation is very poor. Water surface flows in mountainous areas are very severe and water penetration into the earth is low, leading to land erosion and leaching (Mahmodi 2003). Increasing water consumption due to population growth and the emergence of new demand for water have caused a reduction in the available water per capita. Moreover, the increasing demand for water usage in different sectors, such as agriculture, industry and household usage lessens the supply of water for its growing demand. Hence, in Iran, the renewable water usage per capita decreased from 5,500 m^3 in 1961 to 2,100 m^3 in 1997. This value has been further decreased to 1,700 m^3 in 2008 and it is predicted that in 2021, it will reach as low as 1,300 m^3 (Ministry of Energy of Iran 2008). This trend has created problems for the agricultural sector which consumes more than 90 % of usable water. Currently, 0.7 kg of agricultural dry products in Iran is produced per 1 m^3 of water (Ministry of Agriculture of Iran 2012). In light of the projected limitations of water resources in 2021 and also the limitations of high-quality agricultural lands in Iran, the most important challenge for the agricultural sector is agricultural production per unit of water consumption (Maknon 2003). Based on a simple prediction of 90,400,000 people in 2021, if the water consumption remains constant until 2021, the amount of required water would be 130,000,000,000 m^3 in Iran (Keshavarz and Heydari 2004). Obviously, the provision of this amount of renewable water is not possible and any kind of water consumption—e.g., agricultural development for self-sufficiency, export of agricultural products and improvement of health quality by increasing consumption of urban and rural water resources—would be problematic in 2021 (Maknon 2003).

The main challenges for water resources management in Iran include substantial limitations of water resources, uneven precipitation, natural phenomena and drought, reduction of water quality, and lack of investment and financial resources. Several scholars have introduced different limitations and constraints regarding the management of agricultural water. For example, Khazayi and Aali (2001) consider natural and structural barriers, legal problems, unplanned land exploitation and development of irrigation with low efficiency as the most important issues of water resources in the agricultural and rural sectors. In addition, excessive harvesting, lack of integrated management among consumers, lack of management for gathering surface waters, as well as administrative and legal problems have been mentioned by Dehkordi (2003) as the main issues and problems in the agricultural water sector.

Moreover, Rogers and Lydon (2000) believe that inefficiency in water management is the main problem for developing countries. Management of water resources is divided into different sectors and handled by various institutions, without considering the interconnected economic, social and environmental dimensions leading to the villagers' mass migration to urban areas. If the amount of usable water in a village is limited, then it would force the village's households to migrate collectively. Drought and the shortage of usable water have caused a severe drop in wheat production in Iran (Maknon 2003). This problem is more severe in rain-fed lands, which have the majority of wheat-planted areas. The shortage of water and uneven precipitation causes very poor pasture and vegetation coverage and brings about many economic, social and environmental problems (Soltani and Karbasi 2003).

Social and environmental losses cannot be estimated by monetary value alone. In addition to losing work and income, farmers also lose their social security which makes survival difficult for them. Husary et al. (2001) conclude based on a qualitative study that population distribution, economic activities and social issues are strongly influenced by access to water resources. According to this research, rural migrants express lack of access to sufficient water resources for drinking and agriculture as their major reason for migration. They state that if they could access water resources, most of the land owners would come back to the village.

Studies done in Iran also show that water has been recognized as the most important and most limited input for agricultural production (Keshavarz and Heydari 2004), especially in the studied area (Maku city in Iran), where the agricultural water per capita is approximately 1,136 m^3 less than the average amount at the national level (Ministry of Agriculture of Iran 2012).

Moreover, the area of cultivable lands in Maku city is limited and these lands are irrigated by scattered and traditional methods which are considered to be major challenges for the utilization of agricultural water resources in Maku (Khazayi and Aali 2001). In light of these issues, the main purpose of this paper is to study the main limitations of water resources in Maku and their effects on the socioeconomic status of wheat farmers. Accordingly, the objectives of this study are as follows: (1) to identify the significant challenges regarding agricultural water resources in the studied area and (2) to specify the effects of these challenges on the wheat farmers in the studied area. The results of this study would help regional and national planners and policy makers in reviewing the internal policies and appropriation of funding resources, and in developing appropriate strategies to improve the use of water resources in the studied region and enhance the region's agricultural status. In addition, this study's findings may enhance the farmers' awareness and understanding of the optimal allocation of resources. Finally, it will contribute to reducing the negative effects of water resources limitations and can be considered as a step towards human resource development as well as rural and agricultural development.

15.2 Materials and Methods

This study is based on survey research which evaluates the effects of water resources limitations on the socioeconomic status of wheat farmers in Maku city in Iran. The statistical population investigated in this study was wheat farmers in Maku city. In order to address the research objectives, it was required to collect quantitative data from these farmers. However, collecting the data from all wheat farmers in the studied area was expensive and inconvenient. Sampling theory was used in order to reduce the number of wheat farmers in the study to a manageable size by selecting a representative sample (Sekaran 2003). For this purpose, probability sampling—or representative sampling—was used, which is the approach that is the most commonly associated with survey-based research strategies.

The first step in probability sampling is identifying a suitable sampling frame, which is a complete list of all wheat farmers in the population from which the sample will be drawn (Saunders et al. 2009). In this study, the sampling frame was the list of wheat farmers in Maku, which was provided by the Agriculture Ministry of West Azerbaijan Province[1] in Iran. In this list, there are 680 wheat farmers in Maku. The actual sample size was calculated using the following formula:

$$n^a = \frac{n \times 100}{re\%} \tag{15.1}$$

where n^a is the actual sample size required, n is the minimum—or adjusted minimum—sample size, and re% is the estimated response rate expressed as a percentage (Saunders et al. 2009).

For this study, a response rate of 30 % was considered. According to Saunders et al. (2009. p 219), a minimum sample size of the population of 680—which is the number of wheat farmers in Maku—at a 95 % confidence level with a margin of error of 5 % is 50. Based on the above formula, the actual sample size for this study would be as follows:

$$n^a = \frac{50 \times 100}{30} = 166.6 \cong 167 \tag{15.2}$$

The systematic sampling method was used for this study. The primary reasons for using this technique rather than simple random sampling are the convenience and simplicity with which it can be applied (Croucher 2002).

To calculate the sampling fraction that is, the proportion of the total population which is needed to be selected the following formula was used:

$$\text{Sampling fraction } = \frac{actual\ sample\ size}{total\ population} \text{ (Saunders et al. 2009, p. 218)} \tag{15.3}$$

For this study, we have:

$$\text{Sampling fraction} = \frac{167}{680} = 0.25,$$

which means that every fourth case from the sampling frame should be selected.

The survey questionnaire was distributed to 167 wheat farmers and from the respondents, 150 questionnaires were completed, providing a response rate of 89.82 %. It is suggested that the high survey response rate was a corollary of the survey distribution method, which placed a specific emphasis on direct personal visits to the selected wheat farmers in the studied area. Moreover, since the majority of the respondents (51.4 %) were illiterate, the researchers conducted direct verbal interviews with them to fill in the questionnaire. Also, the validity and reliability of the questionnaire were confirmed through the Cronbach's Alpha coefficient ($\alpha = 0.82$) (Kalantari 2003). For the analysis of the collected data, a factor analysis technique was used and all of the analyses were implemented by SPSS software.

[1] West Azerbaijan Province is in the northwest of Iran. Maku is a city in this province.

The dependent variable in this study is the socioeconomic status of wheat farmers. Independent variables include some demographic variables—e.g., age, level of education, source of water used by the studied wheat farmers—and natural, structural and managerial limitations of water sources. These variables were measured using 36 statements which were coded by a Likert scale[2] (Li 2013). A five-point Likert scale—strongly agree, agree, neutral, disagree and strongly disagree—was used to measure natural (12 statements), structural (11 statements) and managerial (13 statements) limitations. These statements have been provided in the appendix.

15.3 Results and Discussion

Collected data show that the average age of wheat farmers is 55 years. The highest frequency belongs to the age range of more than 51 years (52 %) and the lowest one belongs to the age range of less than 30 years, indicating that the majority of wheat farmers in this city are old. The following table shows the frequency of the different levels of literacy among the respondents.

As Table 15.1 shows, the majority of studied farmers (51.4 %) are illiterate and the highest level of education among the respondents is a high school degree (10 %), implying a very low level of literacy among the studied wheat farmers. The mean cultivated area of irrigated and rain fed wheat for each user is about 14 ha and the average number of land pieces is five, which indicates that agricultural lands have been fragmented in this region. Moreover, as Table 15.2 shows, the main source of water in the studied area is semi-deep wells (49.3 %).

15.3.1 Factors Pertaining to the Limitations of Water Resources

Using factor analysis, the variables pertaining to the limitation of water resources are identified. As well, the amount of explained variance for each variable in the form of various factors is obtained. Results of a Kaiser-Meyer-Olkin (KMO)[3] test show that the internal consistency of data is acceptable (KMO = 0.785 > 0.5) and also a Bartlett test shows significance ($p < 0.01$) (Kalantari 2003). In this study, the variables pertaining to the limitations of water resources are summarized into four

[2] The Likert scale is commonly used as a standard scale to measure responses. Using this scale, respondents indicate their level of agreement or disagreement on a symmetric agree-disagree scale for a series of statements.

[3] Kaiser-Meyer-Olkin or KMO measures the appropriateness of data for factor analysis. If the calculated value for KMO is more than 0.7, data are quite appropriate for factor analysis. If this value is less than 0.5, data are not suitable for factor analysis. In any situation where KMO is between 0.5 and 0.7, the results of factor analysis should be interpreted carefully.

Table 15.1 Level of literacy of wheat farmers in Maku city

Level of education	Frequency	Average	Percentage
Illiterate	77	0.514	51.4
Primary school	42	0.28	28
Middle school	16	0.106	10.6
High school	15	0.1	10
Sum	150	1	100

Table 15.2 Source of water used by wheat farmers in Maku city

Source of water	Frequency	Average	Percentage
Semi-deep well	74	0.493	49.3
Pit	40	0.267	26.7
Subterranean	22	0.147	14.7
Springs	14	0.093	9.3
Sum	150	1	100

factors with Eigen-values of more than one. These four factors account for 67.53 % of the variance of the limitations of water resources in Maku city. In the process of factor analysis, after factor rotation by the Varimax method, obtained factors were named according to the variables and their Eigen-values. Table 15.3 shows the Eigen-value and percentage of variance for each factor.

The result of this analysis indicates that the highest Eigen-value is related to the atmospheric and natural conditions, which accounts for 23.33 % of related variance of the limitation of water resources. The next dominant factors include the pattern of water resources utilization, challenges of water resources management and patterns of land utilization, which account for 17.85 %, 14.47 % and 11.88 % of the variance, respectively. Table 15.4 shows the variables pertaining to each factor and the factor loading.

According to the results, the most important factor relating to limitations of water resources is atmospheric and natural conditions. This means that limited access to water resources is mainly due to drought of these sources. As Jin and Young (2001)

Table 15.3 Factors pertaining to agricultural water resources in Maku city

Number	Name of factor	Eigen value	Percentage of explained variance	Cumulative percentage of explained variance
1	Atmospheric and natural conditions	7.18	23.33	23.33
2	Pattern of water resources utilization	4.51	17.85	41.18
3	Challenges of water resources management	3.84	14.47	55.65
4	Pattern of land utilization	1.95	11.88	67.53

Table 15.4 Factors and variables pertaining to the limitation of water resources with factor loading

Factor name	Variables	Coefficient value
1. Atmospheric and natural conditions	Reduction of precipitation	0.711
	Rivers drought	0.620
	Lack of availability of sufficient water resources in region	0.772
	Springs and subterranean droughts	0.712
	Insufficient distribution of precipitation over time	0.632
	Continuing drought in region	0.698
2. Pattern of the water resources utilization	Type of water resources ownership	0.651
	Inefficiency of the irrigation method	0.771
	Wasting of water during its transmission from the source to the farm	0.759
	Development of traditional irrigation methods	0.599
	Over usage of water resources	0.637
3. Challenges of the water resources management	Exporting of water from the region	0.745
	Unknown ownership of the springs	0.780
	Interference of the different organizations in the management of agricultural water resources	0.669
	Conflicts between the farmers regarding the water distribution	0.821
	Lack of sufficient associations for water resources	0.775
	No management for the surface waters	0.788
	Lack of development of new irrigation methods	0.811
	Low irrigation efficiency	0.729
4. Pattern of the land utilization	Type of utilization system	0.818
	Slope of the lands	0.669
	Land fragmentation	0.801
	Traditional utilization system of agricultural land	0.879
	Low mechanized cultivation	0.664

confirm, the agriculture sector is facing a water crisis. How farmers use water resources, is specified as the second factor in this study. Based on the findings, ownership of water sources is usually unknown in the studied area, leading to over usage of these sources. This finding confirms Howarth and Lal's (2002) discovery that lack of proper ownership system for water sources is a significant restricting factor. Water resources management is specified as one of the other important factors in this study. Water resources management contributes to enhancing the efficiency of irrigation methods, achieving optimal accumulation of surface waters, and establishing appropriate institutions for these sources. As Rahimi (2004) shows, inappropriate maintenance of water sources significantly reduces the accessibility of these sources and needs to be solved through an accurate management system.

Table 15.5 Effects of water resources limitations on the socioeconomic status of wheat farmers in Maku city

Number	Name of factor	Eigen value	Percentage of explained variance	Cumulative percentage of explained variance
1	Economic effects	8.99	31.12	31.12
2	Social effects	6.85	22.19	53.31
3	Environmental effects	3.47	14.89	68.20

15.3.2 Effects of the Water Limitations on the Socioeconomic Status of Wheat Farmers

Factor analysis results for the effects of water limitations on the socioeconomic status of wheat farmers in the study area show that the internal consistency of data is significant (KMO = 0.819) and a Bartlett test shows significance ($p < 0.01$), indicating that the data are suitable for entering into the factor analysis. After factor rotation by the Varimax method, variables pertaining to the socioeconomic effects of the water resources limitations are summarized in the form of three factors.

Table 15.5 shows that economic effects with 31.12 % of variance, social effects with 22.19 % of variance and environmental effects with 14.89 % of variance are the most important effects of agricultural water limitations in Maku city, accounting for 68.20 % of variance. Also, Table 15.6 shows the variables pertaining to each factor and the factor loading. All these measured effects are based on the perceptions of respondents who are directly affected by the limitation of water resources.

According to the results, water resources limitations have three main effects on the studied wheat farmers. The first one is the economic consequences of water shortages. Lack of water sources in the studied area causes a significant reduction in farmers' income. It also reduces job opportunities in the agriculture sector, which forces farmers to invest in non-agricultural sectors and migrate to urban areas. This finding has been corroborated by Rogers and Lydon (2000), Husary et al. (2001) and Rashidpour (2011). Moreover, it is found in this study that water resources shortages cause conflicts among rural families, leading to a reduction of participation in group activities and a low quality of life. As Rashidpour et al. (2012) confirm, the social consequences of water resources limitations include increasing poverty among rural families, reduction of food security in regional areas and reduction of life and job satisfaction for farmers.

15.4 Conclusions and Recommendations

The main challenge of this study is to identify the limitations of water resources in the studied area. Based on the opinions of wheat farmers and using factor analysis techniques, these limitations were summarized as four groups of challenges,

Table 15.6 Variables pertaining to socioeconomic factors and consequences with factor loading

Factor name	Variables	Coefficient value
1. Economic effects	Farmers' income reduction	0.774
	Job opportunities reduction in agriculture sector	0.681
	Increasing production costs	0.690
	Product output reduction	0.763
2. Social effects	Increasing conflicts among farmers concerning the distribution and utilization of water resources	0.845
	Welfare reduction among farmers	0.812
	Participation reduction among farmers for the restoration of water resources	0.514
	Increasing seasonal and permanent migration of farmers	0.724
	Intensification of farmers' poverty	0.699
	Farmers' disappointment regarding the water resources restoration	0.699
	Reduction of farmers' satisfaction regarding the agricultural activities	0.841
3. Environmental effects	Transformation of the irrigated lands to dry lands	0.691
	Lands drying	0.755
	Transformation of land usage	0.749
	Degradation and destruction of the pastures	0.827
	Soil quality reduction	0.819

namely, atmospheric and natural conditions, pattern of the water resources utilization, challenges of the water resources management and pattern of the land utilization. To reduce these limitations and their effects on the studied farmers, the following suggestions are given:

1. As drought of water resources is very common in the studied area, the use of drought resistant varieties of wheat and other agricultural crops will be effective in reducing atmospheric and natural limitations, which are unintentional challenges.
2. Wheat farmers use traditional irrigation methods in the studied area. Water sources are significantly wasted through these inefficient methods. It is suggested that new and modern irrigation methods be introduced to the farmers in this area. In addition, providing some training courses on the use of more efficient irrigation methods would be helpful. Since most farmers (51.4 %) are illiterate, it is necessary to educate them about how to save water and prevent over usage of water.
3. Lack of sufficient management of water resources in the studied area is a significant issue, so the use of water resources in this area should be managed in an effective manner. This means that water allocation to the studied farmers

should be fair. It is suggested that responsible agencies or organizations adopt some strategies to enhance the efficiency of water usage in the studied area. These strategies should be based on the regional conditions. Moreover, removing some interfering organizations from water resources management would be effective.

4. Income and job opportunities reduction have been determined as the effects of water resources limitations. In order to reduce these effects, it is suggested that alternative incomes be made available through the creation of new job opportunities. In this way, the capital of farmers is consolidated in the regional area and their migration to urban areas is prevented, leading to an increase in satisfaction among the farmers with regard to agricultural and rural activities. This helps farmers to make significant contributions to the development of their regional areas.
5. Since the pattern of land utilization in the studied area is inappropriate and the lands are highly fragmented, it might be helpful if agricultural lands are integrated and agricultural production cooperatives are initiated to allow for large-scale agricultural activities. As a consequence, the quality of the soil would be improved and land degradation would be prevented. This would also increase the environmental stability of the region.

15.5 Future Work

According to the results of this study, farmers do not pay attention to the water requirements of crops and the cropping pattern does not match the climate conditions of the studied region. It is therefore highly recommended that research concerning the accurate determination of the water requirements of different crops be carried out. Furthermore, as lack of precipitation and drought of water sources are rampant in this area, a feasibility study of the cultivation of drought resistant crop varieties and the establishment of systems resilient to erratic precipitation would be useful.

Acknowledgment The authors would like to thank the anonymous reviewers who gave valuable suggestions that have helped to improve the quality of this paper.

Appendix

Since this study was done in a small city in Iran, the survey questionnaire was prepared in the Persian language. However, the statements used to measure water sources limitations and their effects have been translated into English and are presented here.

Extent to which you agree with the following statements:

Limitation	Statements	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Natural limitations	1. Precipitation has been reduced significantly in recent years in my area					
	2. Surface water sources have been reduced significantly in recent years in my area					
	3. Rivers drought can restrict our access to water sources significantly					
	4. Surface water sources are wasted due to the sharp slope of the lands					
	5. There is a lack of the availability of sufficient water sources in the region					
	6. There is a very low availability of surface water sources					
	7. Springs and subterranean droughts can restrict our access to water sources significantly					
	8. Rivers have many meanders, leading to waste water					
	9. Insufficient distribution of precipitation over time is one of the major problems in my area					
	10. There is a significant leakage from the surface of creeks					
	11. My area has a continuous trend of drought					
	12. A significant amount of water sources is used up by the surrounding weeds					
Structural limitations	1. The type of the water resources ownership affects our access to water sources					
	2. Irrigation methods are inefficient in my area					
	3. The type of utilization system affects our access to water sources					
	4. Water sources are wasted during water transmission from the source to the farm					

(continued)

(continued)

Limitation	Statements	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
	5. The irrigation methods are very old and traditional in my area					
	6. There is an over usage of the water sources in my area					
	7. Lands are highly fragmented in my area, leading to the waste of water sources					
	8. The utilization system of agricultural lands is traditional in my area					
	9. Cultivation is very low mechanized in my area					
	10. Surface water sources are contaminated with rubbish in my area					
	11. There is a long distance from water sources to farms					
Managerial limitations	1. Water is being exported from my region					
	2. The ownership of springs is unknown					
	3. Management of agricultural water sources is dealt with by different organizations					
	4. There is conflict between farmers regarding the water distribution in my area					
	5. There is a lack of sufficient associations for water sources in my area					
	6. There is no management of the surface waters in my area					
	7. Responsible bodies do not develop new irrigation methods in my area					
	8. Irrigation efficiency is low in my area					
	9. There is an excessive usage of water sources by farmers in my area					
	10. Livestock pass through water sources, which highly pollutes the water					
	11. Water piping costs are high					
	12. Local people use water sources for non-agricultural purposes					
	13. There is a poor drainage system in my area					

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Chapter 16
Impact of Climatic and Anthropogenic Factors on Groundwater Irrigation in South India

T. Mohanasundari and R. Balasubramanian

Abstract Climate change poses tremendous uncertainties to the supply and management of water resources. Given the importance of groundwater in agriculture and domestic water supply for numerous rural communities in South India, this paper seeks to address the impact of climate change on groundwater supplies and possible policy interventions to mitigate the problem. The study site is the Tamil Nadu state in South India where groundwater aquifers are already under severe stress due to poor management caused by perverse incentives such as fully subsidized electricity for groundwater pumping and absence of regulatory policy and/or institutions. This study attempts to quantify the impact of climate change and other man-made factors such as electricity pricing regime and well density on groundwater levels and groundwater irrigated area. Using panel data econometric approaches, the factors affecting depth to water table and area irrigated by wells were identified and quantified. The fixed effects panel data model and panel corrected standard errors methods were employed for analysis. Both current rainfall and lagged rainfall were found to have positive impact on groundwater table and area irrigated by wells, while the increase in number of wells (well density) and shift in electricity pricing from a pro-rata regime to a fully subsidized pricing regime lead to significant negative impact on water table and area irrigated per well. The study concludes that climate change and other anthropogenic factors such as increased exploitation of groundwater and ineffective pricing of electricity will clearly lead to unsustainable groundwater levels. Therefore, appropriate

This paper is based partly on the Masters' degree dissertation work carried out by the first author under the guidance of the second author and also forms part of the research project carried out by the second author under a grant from South Asian Network for Development and Environmental Economics (SANDEE), Kathmandu, Nepal. The financial support from SANDEE is gratefully acknowledged.

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K.W. Hipel et al. (eds.), *Conflict Resolution in Water Resources and Environmental Management*, DOI 10.1007/978-3-319-14215-9_16

policies such as pro-rata pricing of electricity and regulation of well drilling will help to mitigate the twin-problems of declining water table and increasing externalities in groundwater irrigation.

Keywords Climate change · Groundwater · Electricity pricing · Tamil Nadu · Irrigated agriculture

16.1 Introduction

Availability of water at a sustainable quality and quantity is threatened by many factors, of which climate plays a leading role. Climate change poses tremendous uncertainties to the supply and management of water resources. Global climate changes that have important implications for water resources include reduced precipitation, increased evaporation of available surface water and transpiration, increased water temperatures, and decreased water quality in both inland and coastal areas. Climate change that reduces either the overall quantity of water or the timing of when water is available for use will have important effects on agricultural, industrial and urban development. Climate-induced water scarcity is expected to become an ever-increasing problem in the future, for various reasons. First, the distribution of precipitation over space and time is very uneven, leading to tremendous temporal variability in water resources worldwide (Oki and Kanae 2006). Second, rate of evaporation varies depending on temperature and relative humidity, which impacts the amount of water available to replenish groundwater supplies.

Several studies show that climatic change is likely to impact significantly upon freshwater resources availability (Kundzewicz and Döll 2009; Döll 2009; Ficklin et al. 2010; Taylor 2012). In India, demand for water has already increased over the years due to urbanization, agricultural expansion, increasing population, rapid industrialization and economic development. At present, changes in cropping pattern and land-use pattern, over-exploitation of water storage and changes in irrigation and drainage are modifying the hydrological cycle in many climate regions and river basins of India. The combination of shorter duration but more intense rainfall (meaning more runoff and less infiltration) combined with increased evapotranspiration (the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere) and increased irrigation is expected to lead to groundwater depletion (Konikow and Kendy 2005).

Since roughly 52 % of irrigation water consumption across India is met from groundwater, understanding the climate change impact on irrigated agriculture, farm economy and food security is of utmost importance to improve our knowledge about the impacts of climate change on groundwater. Shah (2009) argues that western and peninsular India are groundwater hotspots from climate change point of view. In many parts of India, and particularly in the hardrock and coastal aquifers of South India, groundwater overexploitation and saline ingress from seawater are common (Planning Commission 2007; World Bank 2010). In addition to its impact on groundwater recharge, climate change will also increase the use of groundwater. If the availability of surface water shrinks, groundwater use usually increases. Where groundwater is already the dominant water resource, the amount of water used could increase due to higher demands as a result of high evaporation rates. For example, in India, 50 % of water used for irrigation comes from groundwater, and in some areas groundwater levels are dropping rapidly. If higher groundwater extraction rates are combined with reduced recharge rates, groundwater resources will become depleted relatively quickly (Ludwig and Moench 2009). Therefore, aquifer exploitation strategies must be adapted to climate variability and climate change (Loáiciga 2003). As unmitigated hydro-climatic variability is linked to poor economic growth of developing countries, groundwater needs to be protected, and its use and maintenance adapted to climate change. Preventing groundwater degradation and unwise exploitation will prove more cost-effective than trying to clean up and restore mismanaged aquifers.

This chapter is the outcome of research carried out at district level to quantify the impacts of climate change on underground water resources and recommends directions for mitigating the impact of climate change on groundwater resources in the context of South Indian state of Tamil Nadu.

16.2 Methodology

16.2.1 A Brief Description of Study Site

The study site is the Tamil Nadu state in South India where groundwater aquifers are already under severe stress due to poor management caused by perverse incentives such as fully subsidized electricity for groundwater pumping together with the absence of appropriate institutional arrangements for regulation of groundwater exploitation. More than 70 % of Tamil Nadu state is underlain by low-storage aquifers, which are heavily exploited (Foster and Garduño 2004). As surface water resource potential in the state has been fully exploited, groundwater assumes enormous significance. Groundwater irrigation in the state has expanded rapidly in the last five decades due to the decline and/or instability in surface irrigation sources, massive expansion in rural electrification, the advent of modern well-drilling technologies, and subsidized supply of electricity for groundwater pumping. Groundwater overexploitation is reported in more than one-third of blocks[1] in Tamil Nadu (CGWB 2011) (Fig. 16.1).

[1] Block is a district sub-division for the purpose of development administration in India. The data on groundwater recharge and pumping volumes are estimated at block level.

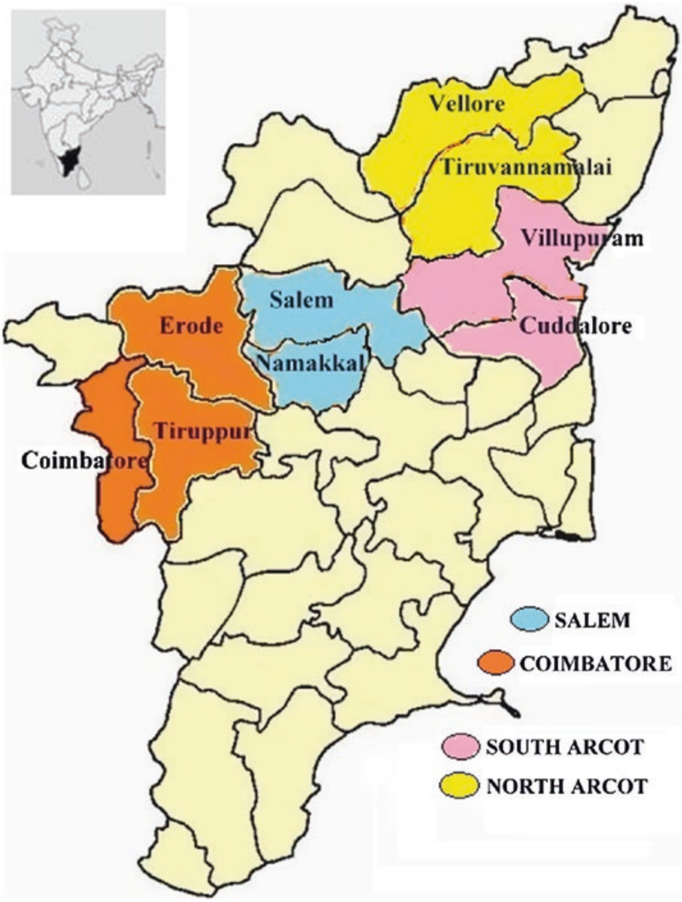

Fig. 16.1 Map of the study area

16.2.2 Conceptual Overview

Several scholars (Balasubramanian 1998; Chen et al. 2001; Bloomfield et al. 2003; Ferguson and George 2003; Ngongondo 2006) have modeled the impact of climate and non-climate variables on water table depth. Two broad approaches have been used in the literature to study the impact of climate change on groundwater resources. The first is the physical approach wherein the changes in groundwater reserves are quantified by physical measurements using hydrological modeling such as water balance method or GIS and simulation modeling. The second is the empirical or statistical modeling approach where the changes in groundwater levels are estimated statistically through building statistical relationship between groundwater level and rainfall, temperature, and other variables.

Regression analysis incorporating climate- and/or non-climate variables has been used by many researchers to study the impact of these variables on water table levels (Ferguson and George 2003; Ngongondo 2006; Palanisami and Balasubramanian 1993; Balasubramanian 1998). Using regression analysis of groundwater levels with monthly rainfall data, Bloomfield et al. (2003) predicted groundwater levels under different future climates and found that even with a small increase in total annual rainfall, the annual groundwater-level could fall in the future due to changes in seasonality and increased frequency of drought events.

Chen et al. (2001) estimated the impact of climate change on groundwater in the Edwards aquifer in Texas, USA using a regional regression model. The recharge into the aquifer was predicted using a log-linear function with monthly recharge as the dependent variable and monthly average temperature and monthly total precipitation as explanatory variables, for the period 1950–1976. Separate regression equations were estimated for each month using 47 years of observations. In most regressions, the temperature variable had expected negative correlation while precipitation had positive correlation with respect to aquifer recharge. These results were then used in a regional economic and hydrological simulation model (EDSIM) to quantify the welfare loss associated with climate change, which was estimated to be in the range of US$2.2–6.8 million per year.

The method for assessing the impact of climate change on groundwater resources must not only account for temporal variations in the climatic variables and their impact on the hydrologic cycle, but also consider the spatial variation of surface and subsurface properties across the study area. The proposed research aims to disentangle the climatic, hydro-geological and socio-economic factors affecting groundwater dynamics. A conceptual model of the interrelationships between climatic- and non-climatic factors affecting groundwater recharge, groundwater availability and extraction, economic policies affecting groundwater utilization and adaptive strategies are provided in Fig. 16.2.

16.2.3 Data and Analytical Approach

The present study has focused on four agriculturally important districts of the state viz., the composite South Arcot, North Arcot, Salem and Coimbatore districts. These districts were purposefully selected on the basis of having comparatively larger share of area benefiting from groundwater irrigation accounting for more than 40 % of the total cropped area of the respective districts and more than 70 % of the total irrigated area of these districts.

Monthly time-series data on groundwater levels for all the observation wells for the period 1972–2010 were collected from the State Ground and Surface Water Resources Data Centre of the Public Works Department, Government of Tamil Nadu. The monthly time-series data on water level were collapsed into annual time-series in order to make these data congruent with other socio-economic variables such as well density and surface irrigated area, which are available only on an

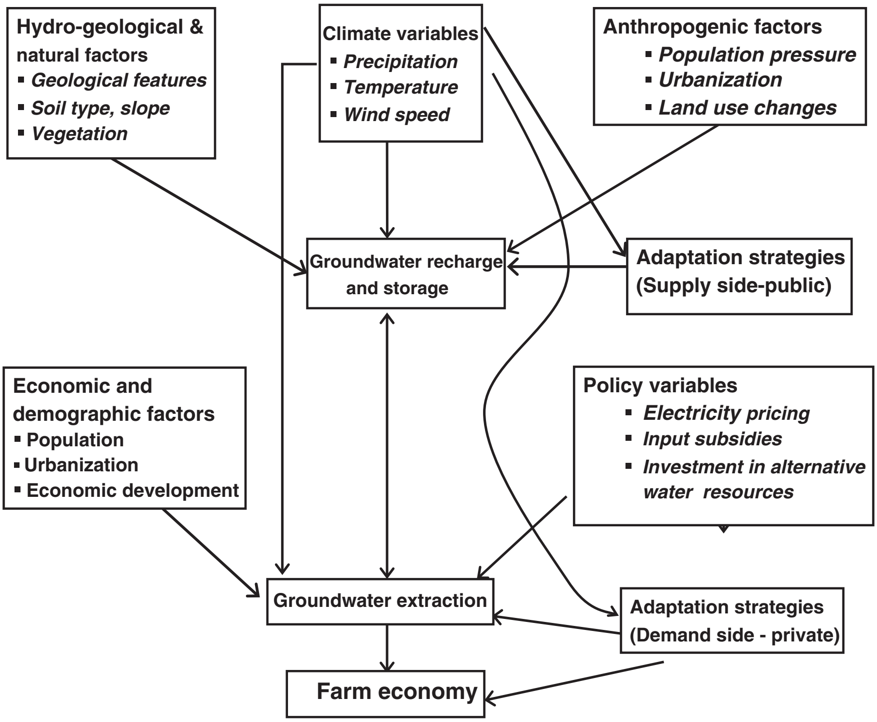

Fig. 16.2 Conceptual model of dynamic Interrelationships between climatic and non-climatic factors, groundwater recharge, adaptation strategies and economic variables

annual basis. The yearly time-series water level data thus generated was regressed on the climate variable (rainfall), area irrigated by surface water sources such as canals and tanks, well density, and a dummy variable for electricity pricing structure.

16.2.3.1 Analysis of Variables Affecting Water Level (Depth of Water Table)

The depth to the water level was estimated using the fixed effects panel data approach. As there was no heteroscedasticity or autocorrelation problem, the fixed effects panel regression model was chosen. Econometric analysis was done using STATA 11.

The estimated multiple linear regression equation is given below:

$$Watlev_{it} = \alpha_1 Temp_{it} + \alpha_2 Rain_{it} + \alpha_3 Wellden_{it} + \alpha_4 Surf_{it} + \alpha_5 Elec_{it} + \alpha_6 Time_{it}$$

where,

Watlev	Water level
Temp	Temperature
Rain	Rainfall

Wellden Well density (total number of wells per ha of total geographical area of the district)
Surf Percent of surface irrigated area
Elec Dummy variable for electricity price
= 0, if electricity was priced on pro-rata basis (i.e. Pricing electricity per unit basis)
= 1, for flat rate or 100 % subsidy for electricity
Time Time
i ith cross-sectional units {i = 1, 2, 3, 4 (districts)} and
t *t*th time period {t = 1, 2, … 39 (years)}

16.2.3.2 Analysis of Variables Affecting Area Irrigated Per Well

The area irrigated per well measure is an indicator of water availability in wells and efficiency in use of irrigation water. The fixed effects panel regression method was chosen for analyzing the area irrigated per well. The dummy variable is used to study the impact of change in electricity pumping from a pro rata basis to zero marginal cost pricing on the area irrigated per well.

The estimated regression equation is given below:

$$\begin{aligned} Apwell_{it} = {} & \beta_1 Temp_{it} + \beta_2 Rain_{it} + \beta_3 LRain_{it} \\ & + \beta_4 Surf_{it} + \beta_5 Watint_{it} + \beta_6 Elec_{it} \end{aligned}$$

Notice that we have put the subscript *i* on the intercept term to suggest that the intercepts of the four districts may be different;
where,

Apwell Area irrigated per well
Temp Temperature
Rain Rainfall
LRain Lagged Rainfall
Surf % of surface irrigated area to gross irrigated area
Watint % of area under water intensive crops (rice, banana, turmeric, sugarcane and coconut) to gross irrigated area
Elec Dummy variable for electricity pricing as defined above
i ith cross-sectional units {i = 1, 2, 3, 4 (districts)} and
t *t*th time period {t = 1, 2, …, 39 (years)}

16.2.3.3 Impact of Climate Change (Rainfall) and Well Density on Private and Social Costs of Groundwater Use

(i) **Impact on social costs of groundwater pumping**

As both rainfall and temperature are found to be the significant factors affecting the depth to water table and area irrigated per well, a reduction in rainfall and/or an increase in temperature will lead to a lowering of water table thus increasing the costs of pumping water. Hence, it is necessary to estimate the impact of rainfall variability and increase in temperature on pumping costs. Using the estimated partial regression coefficients of climate variables (rainfall and temperature), the mean depth to water table and the unit cost of electricity to lift water by one metre, it is possible to compute the changes in pumping costs as a consequence of climate change. In the present study, the increase in pumping costs were worked out for a 10 % decrease in rainfall due to climate change in the long term and by assuming an increase in temperature by 1 °C. The increased cost of pumping is called social cost due to the fact that electricity is supplied to farmers at full subsidy and hence there are no private costs of pumping to the farmers.

(ii) **Estimation of change in farm income due to climate variability**

By using the partial regression coefficient for climate variables in the regression analysis of factors affecting area irrigated per well, it is possible to estimate the reduction in well irrigated area due to decrease in rainfall and increase in temperature. After estimating the total reduction in the well irrigated area, it is possible to estimate the reduction in farm income by using the differential farm income between well-irrigated farms and rainfed farms in the state. The mean difference between incomes from well-irrigated and rainfed farm has been estimated to be Rs. 8,670 per ha as per the study conducted by Balasubramanian and Raveendaran (2009). Similar to the pumping costs estimation, we have assumed a 10 % decrease in rainfall and a 1 °C increase in temperature over the long term to estimate their impact on area irrigated by wells and the consequent impact on farm income.

16.3 Results and Discussion

16.3.1 Growth of Well Irrigation in the Study Area

The results of growth rate analysis are presented in Table 16.1. There has been a steady increase in the number of tube wells over the last five decades because of the deterioration of surface irrigation together with the development of modern well-drilling and water extraction mechanisms. This is evident from moderate to high growth rate in the number of tube wells in the districts studied. Due to increasing intensity of competition among well owners in extracting ground water and the consequent over-extraction of groundwater, the number of failed wells has shown an increasing trend over the years as reflected in the significant positive growth in their numbers. The number of open well did not show significant growth due to the advent of modern technology for drilling tube wells and deep bore wells which enables less time- and cost-intensive methods of well drilling as compared to the traditional open wells. Both canal irrigated area and tank irrigated area have shown a negative growth rate, which implies that the scope for further expansion in surface irrigated area is extremely limited. Other sources do not have much

Table 16.1 Growth rate of net irrigated area in the study area, 1960–2010 (compound growth rates in percent)

Particulars	Coimbatore	Salem	South Arcot	North Arcot
No. of tube-wells and bore-wells	24.48	25.04	9.89	5.19
No. of open wells	1.11	1.24	1.48	1.21
No. of failed wells	2.24	2.75	1.2	1.94
Area irrigated by canals	−1.42	1.75	−0.94	−5.18
Area irrigated by tanks	−3.49	−2.56	−2.67	−3.67
Area irrigated by tube-wells and bore-wells	23.69	22.2	8.65	7.13
Area irrigated by open wells	0.70	1.82	1.16	1.81

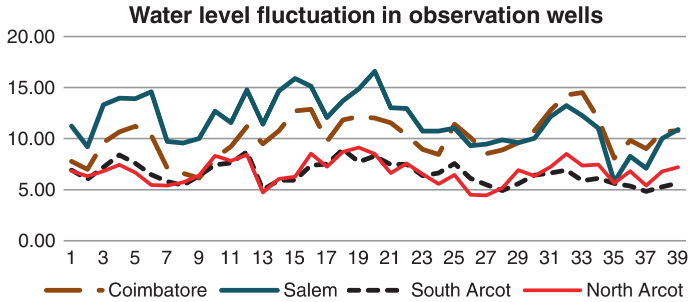

Fig. 16.3 Water level fluctuation in observation wells

impact towards area irrigated. The area irrigated by tube wells has been increased over a prolonged period to 23.69, 22.20, 8.65, and 7.13 % in Coimbatore, Salem, South Arcot, and North Arcot respectively. Consequent to the continuous growth in number of wells, area irrigated per well has declined in all the districts probably due to the increasing interference among wells and the overexploitation of groundwater.

The graph exhibits a wide fluctuation in water table depth due primarily to the fluctuating trend in rainfall. The fluctuation followed a similar trend in all the districts except in Coimbatore where the fluctuation was much less and the depth to water table has shown a marginal increasing trend over time (Fig. 16.3).

16.3.2 Regression Analysis of Depth to Water Table

The summary statistics of the variables used in the regression analysis of water table depth are provided in Table 16.2. The mean area irrigated per well is 1.38 ha with a standard deviation of 0.74 and the values ranged from 0.40 to 4.61 ha across different districts over time. Since the data pertain to a relatively long period of five decades with wide variation in rainfall, the number of wells and the

Table 16.2 Descriptive statistics of variables

Variables	Mean	Std. dev	Minimum	Maximum
Water level (m)	8.81	2.83	4.44	16.59
Area irrigated per well (ha)	1.38	0.74	0.4	4.61
Well density (# of wells per ha)	0.175	0.058	0.09	0.28
% surface irrigated area	4.23	3.94	1.12	22.38
Rainfall (mm)	922	249.4	440	1,620
Lagged rainfall (mm)	922.6	250.63	440	1,620
Temperature (max)	33.25	0.84	31.37	34.80
Time	20	11.29	1	39
Electricity dummy	0.667	0.473	0	1

area irrigated by alternative sources of irrigation, the area irrigated per well varied over a wide range. Well density has the mean value of 0.16 implying that there are 16 wells in an area of 100 ha and it ranges from a minimum of 0.06 to a maximum of 0.28. The percentage of canal irrigated area had a mean of 3.53 and a standard deviation of 2.70. Mean rainfall of the study area was 926.06 mm and the standard deviation was 254.77. The minimum rainfall was 440 mm and the maximum was 1,620 mm rainfall which shows almost four-fold spatial-temporal variability. This provides adequate scope to capture the impact of rainfall variability on water table depth and area irrigated per well.

The results of regression analysis of factors affecting depth to water table are presented in Table 16.3. The independent variables viz., current period and one-period lagged rainfall were found to have negative impact on water level, that is, as rainfall increases, the depth to water table decreases because the water table in the aquifer rises up in response to the increase in rainfall. Similar effect was noticed in the case of percent of surface irrigated area implying that as surface irrigation increases it leads to increased recharging of aquifers thereby resulting in reduced depth to water table (a rise in water table in the aquifer). However, increase in well density leads to intensive extraction of groundwater thus resulting in increased depth to water table. Thus well density had a positive correlation with depth to water table. An important policy-relevant inference from the analysis

Table 16.3 Regression analysis of the depth to water table of the well (fixed effects panel regression model)

Variables	Coefficient	Std. error	t-value
Constant	−12.75*	7.8356	−1.63
Temperature	0.7687**	0.232	3.31
Rainfall	−0.0034**	0.0007	−5.14
Well density	7.6331	6.347	1.20
% of surface irrigated area	−2.5684*	1.5056	−1.71
Electricity price dummy	0.9122**	0.4478	2.04
Time	−0.0787***	0.0175	−4.48

Note ***, ** and * indicate statistical significance at 1, 5 and 10 % levels respectively is that the dummy variable for electricity pricing is positive and significant at 5 % level indicating that the depth to water table increased after the introduction of flat rate system of electricity pricing. This is quite an expected result, as marginal cost of pumping water becomes zero (due to flat rate pricing electricity) farmers pump water from deeper aquifers using modern water extraction mechanisms. Hence, pro-rata system of electricity pricing is necessary to prevent aquifer over-exploitation. The coefficient of the time variable is found to be negative indicating that time has the effect of reducing the depth to water table. This is probably due to the improvements in water use such as drip irrigation technology and/or water conservation technologies such as watershed developments which might have contributed to increases in the water table over time.

16.3.3 Regression Analysis of Area Irrigated Per Well

The results of the regression analysis of factors affecting area irrigated per well are furnished in Table 16.4.

Temperature has significant effect on area irrigated per well possibly due to higher water requirement per unit area of crop thus resulting in lesser area irrigated by groundwater. Though current year rainfall was not found to be significant, one period lagged rainfall has significant positive impact on area irrigated per well. The dummy variable for electricity pricing is negative and significant at one percent level indicating that the area irrigated per well has declined due to the introduction of flat rate pricing of electricity. This is primarily due to the increase in groundwater pumping and increased area under water-intensive crops after the introduction of a flat rate pricing regime (Balasubramanian 1998). The increase in percentage share of surface irrigated area to total irrigated area had a positive influence on area irrigated per well indicating that the groundwater recharge effect of surface irrigation plays a significant role in increasing well irrigated area. The results of regression analysis indicate that both climate and anthropogenic factors have significant impact on groundwater resources.

Table 16.4 Regression analysis of area irrigated per well

Variables	Coefficients	Std. error	t-value
Constant	2.2461***	0.8677	2.59
Temperature	−0.0450*	0.0257	−1.75
Rainfall	0.0000	0.0001	0.01
Lagged rain	0.0001*	0.0001	1.94
% of surface irrigated area	−0.6503***	0.1624	−4.00
% of area under water intensive crops	0.5725***	0.1750	3.27
Electricity price dummy	−0.1053***	0.0346	−3.04

Note ***, ** and * indicate statistical significance at 1, 5 and 10 % levels respectively

16.3.4 *Impact of Climate Change on Private and Social Costs of Groundwater Use*

(i) **Impact on social costs of groundwater pumping**

As both temperature and rainfall are found to have significant impact on water table and area irrigated per well, increase in temperature and possible decrease in rainfall due to climate change will lead to a lowering of water table thus increasing the social costs of pumping water. Similarly, the negative impacts of increased temperature and reduced rainfall on area irrigated per well, will result in a switch to unirrigated crops at least in regions where groundwater is the mainstay of agriculture. This will lead to lower profitability at farm level besides leading to food security issues. Hence, the impacts of climate change on social costs of pumping and area irrigated by wells and its consequences on farm income were estimated using the results of regression analysis presented in the preceding sections.

The impact of an increase in temperature and decline in rainfall on cost of pumping were estimated in order to project the impact of these variables in monetary terms. A one degree Celsius increase in temperature will increase the electricity consumption by 310 kilo Watt hour (kWh) per single well. Cost of this increased electricity consumption is Rs. 1,550 per well and the total cost for all wells in the state is about Rs. 2,846 million. A 10 % decrease in rainfall will increase the electricity consumption by 334 kWh per well. The increased pumping cost is estimated to be Rs. 1,670 per well and Rs. 3,066 million for all the wells in the state (Table 16.5).

(ii) **Impact of temperature and rainfall on area irrigated by wells**

The impact of increase in temperature and decrease in rainfall on area irrigated per well and its consequent monetary effect on farm economy are presented in Table 16.6. An increase in temperature by one degree Celsius reduces the well

Table 16.5 Impact of temperature and rainfall on social cost of electricity consumption

Change in climate variables	Electricity consumption per well (kWh)	Increased cost of pumping per well (Rs.)	Increase in pumping cost for total wells in the state (Million Rs.)
1 °C increase in temperature	310	1,550	2,846
10 % decrease in rainfall	334	1,670	3,066

Table 16.6 Impact of temperature and rainfall on area irrigated by wells

Change in climate variables	Reduction in total well irrigated area (ha)	Loss in farm income due to reduced acreage under irrigation (Million Rs.)
1 °C increase in temperature	24,738	214.48
10 % decrease in rainfall	43,956	380.98

irrigated area by 24,738 ha in the state. The loss in farm income due to the reduced area under well irrigation is estimated to be Rs. 214.48 million. A 10 % decrease in rainfall will result in reduction of 43,956 ha in the well irrigated area and the consequent loss in farm income was much higher at Rs. 380.98 million per year.

16.4 Conclusion

This study has highlighted the impact of climate change on the depth to groundwater table and area irrigated by groundwater. Both climatic variables such as temperature and rainfall, and man-made factors viz., inefficient electricity pricing, over-extraction of groundwater as reflected by increasing well density, and area under water-intensive crops, have significant impact in lowering the water table and reducing area irrigated by groundwater. Another important reason for the underground resource depletion is that water rights are linked with land ownership. This virtually makes many aquifers open access resource to land owners. Lack of legal and institutional mechanisms for regulating the use of groundwater is yet another confounding factor. The diversity of groundwater occurrence due to climate change coupled with changing patterns of human use of water and land present a complex system of resource management. As pointed out by Dhawan (1991) pump set technology combined with advances in groundwater boring technology is a dangerous development from the view of groundwater conservation.

The major challenge for the future is to stabilize the aquifers which exhibits serious hydraulic imbalance, especially in the light of climate change. Well density is increasing continuously and it is a clear sign of increasing inter-well externality among wells since more and more wells share the same quantum of water available in the aquifers. Consequently, as demonstrated by the econometric analysis, increasing well density has significant negative impact on groundwater irrigation by lowering the water table. Therefore, appropriate policies are necessary to ensure the ever-increasing trend in number of wells as well as indiscriminate digging of deep bore wells. The existing norms for well spacing should be implemented strictly to ensure that the well interference is mitigated to the maximum possible extent.

As the study revealed, the introduction of a flat rate pricing system/full subsidy for electricity has clearly resulted in increase in depth to water table and reduced the area irrigated per well. Shah (2007) and Dhawan (1993) argued that full subsidy for electricity is an important factor fuelling the increasing number of wells and the water quantities being pumped from aquifers, canals, streams and rivers in the Tamil Nadu. Subsidized, agricultural electricity use has created a number of negative externalities. Therefore, an appropriate pricing system, preferably pro-rata pricing regime which will ensure positive marginal cost of pumping is essential to mitigate the problem of declining water table and increasing diseconomies in groundwater irrigation.

Economic incentives should be developed to encourage reduced water consumption. Adoption of water-saving technologies such as drip and sprinkler irrigation is quite effective in achieving efficient groundwater use. In many states of

India, farmers use expensive energy to pump groundwater but then lose much of it in evaporation and seepage by conveying it in earthen field channels. It is suggested the promoting piped conveyance can save a great deal of energy and water from wastage. To address the problem of resource degradation and water scarcity in drought prone areas, stakeholders and policymakers need to promote the community-based watershed management programmes effectively.

Surface irrigation sources especially canal irrigation systems provide a fairly good amount of recharge of aquifers. This will in turn mitigate the problem of declining water table. Seepage water from canals should be channeled to recharge groundwater aquifers (Shah 2009). Groundwater recharge programmes such as rainwater harvesting through watershed development and percolation ponds require adequate incentives together with good planning, design and operation with proper monitoring. Safeguarding and enhancing the benefits from groundwater under climate change will only be possible through dedicated efforts and diligent development and management strategies.

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